Cape Verde Wind Farms

Step 2

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Cape Verde Wind Farms

Step 2

Feasibility Report

Vol. 1

CROSSCUTTING ANALYSIS
AND
DRAFT PROJECT DOCUMENT

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RISØ and ElsamProjekt

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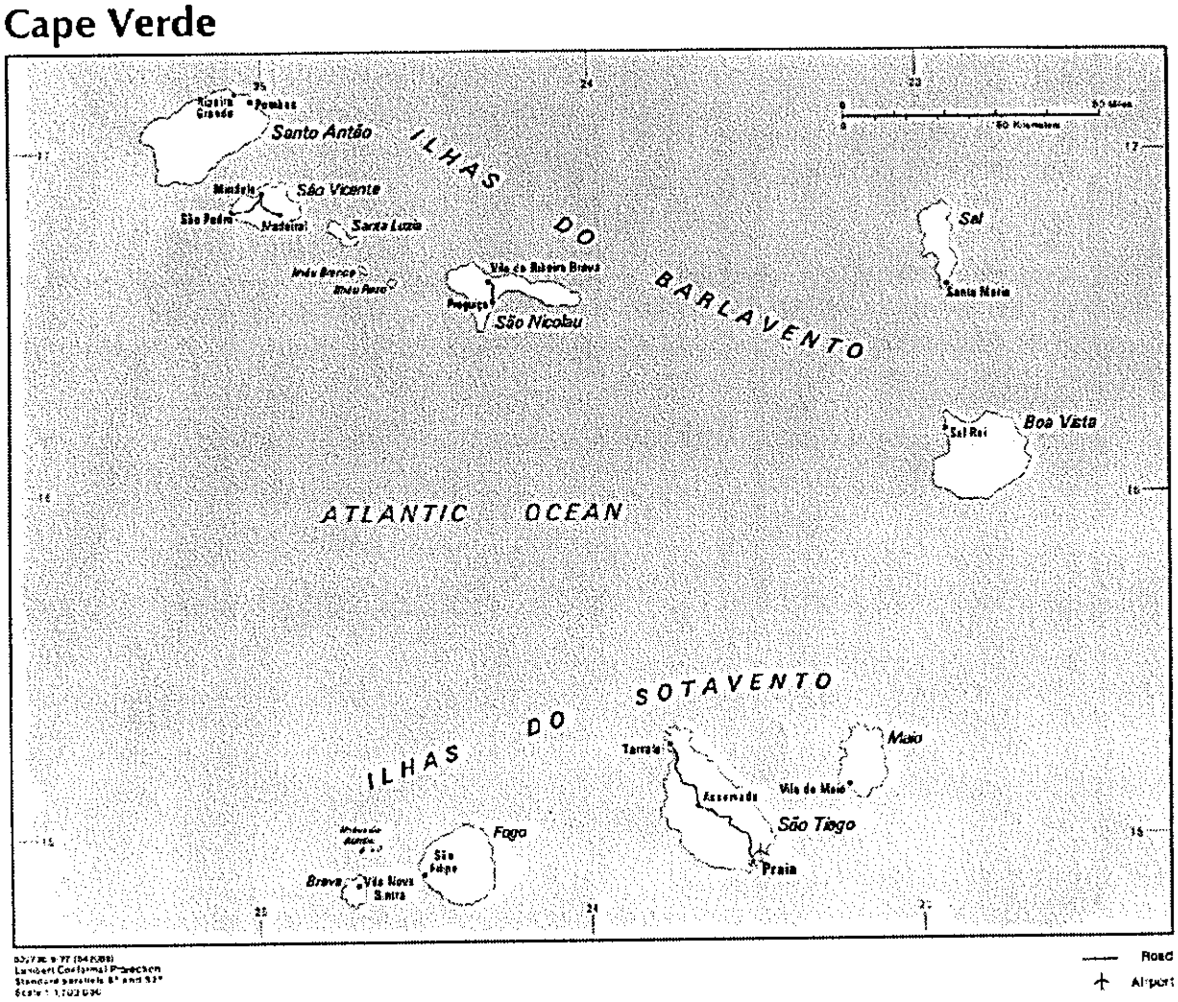
Figure 1 Cape Verde



List of abbreviations

ELECTRA - Empresa Publica de Electricidade e Agua
DGIE - Directorate General of Industry and Energy in Ministry of Economic Cooperation
FS - Feasibility Study
LPC - Levelized Production Costs
NPV - Net Present Value
IRR - Internal Rate of Return
DKK - Danish kroner
ECV - Cape Verde escudos
USD - US dollars

1. Introduction

The Wind Farm Project agreed between the Cape Verdean and Danish governments consists of

- Step 1 Wind Farms in the ELECTRA power systems at Praia, Mindelo and Sal with a total installed wind turbine capacity of 2.4 MW
- the Feasibility Study (FS) of the possibilities for expanding the Step 1 Wind Farms with Step 2 Wind Farms at Praia, Mindelo and Sal.

The Cape Verde Wind Farm Project was effectively started in June 1992. The Step 1 Wind Farms have been completed and handed over to ELECTRA in December 1994. The present report concerns the feasibility study for Step 2 Wind Farms. The results of the FS are summarized in this Vol. 1, whereas Vol. 2 and Vol. 2 Appendices give the technical and economic analyses and further details. In addition to the technical analyses assumptions and results necessary for investigating the feasibility of the Step 2 wind farms, Vol. 2 also contains theoretical details on wind power and power system operation discussed with ELECTRA throughout the FS as part of the institutional collaboration between ELECTRA and Risø.

The team of consultants for performing the FS was

Jens Carsten Hansen, Risø National Laboratory
John Olav Tande, Risø National Laboratory
Niels Juhl Thomsen, Risø National Laboratory (presently Carl Bro A/S)
Peter Skjerk Christensen, Risø National Laboratory
Per Nørgård, Risø National Laboratory
Per Lund, Elsamprojekt A/S

The FS was carried out in close collaboration between the team of consultants and ELECTRA, supervised by the project steering committee. The project steering committee consisted of:

Antao Fortes, Director General of Industry and Energy (DGIE), Ministry of Economic Coordination
Pedro Alcantara Silva, Director of Center of Renewable Energy (CER)
Joao Fonseca, Technical Director, Engineering Department, ELECTRA

ELECTRA project manager was Jansenio Delgado. Deputy project manager was Jorge Pereira.

2. Background

2.1 Cape Verde

The Republic of Cape Verde is an archipelago of 9 inhabited islands located in the Atlantic Ocean 600 km west of the African continent at latitudes 15-17°N and longitudes 23-25°W. Cape Verde has been an independent republic since 1975.

The climate of Cape Verde, being on the equatorial side of the subtropical high-pressure systems at 30°N and north of the equatorial trough with a relative low-pressure, is a trade wind climate for most of the year except for short periods between July and October. The trade winds are known for their extreme constancy in speed and direction - more so than in

Table 1 Cape Verde key data.

Inhabited islands	9
Area	4000 km^2
Population (1990)	350 000
Capital	Praia
Avg. temperature	24° C
Annual rain fall	300 -600mm

any other climate zone - which is also what is found in the wind data recorded at Sal International Airport and by previous wind energy projects in Cape Verde. During July-October from time to time the climate changes from trade winds to other types of weather bringing changing wind directions other than the NE or ENE and less steady winds - even periods with calms - as well as occasional heavy rains. The rainfall, however, is totally low and only a few days a year. Cape Verde is one of the so-called Sahel countries, signifying an extremely dry climate. Though the islands e.g. at Praia gets typically 300 - 600 mm of rainfall annually, the evaporation is high and the terrain and its geology is such that only a part of the rainfall remains as ground water.

The lack of fresh water and the lack of electric energy are core problems for the development of Cape Verde. The country imports diesel fuel for electricity production for conventional consumption and for production of fresh water which is done by desalination of sea water. The wind resources can be utilized for electricity production, saving imported fuel and reducing the cost of electricity and desalinated sea water.

Praia is the capital of Cape Verde and houses about 24 % of the Cape Verde population, whereas about 15 % lives in Mindelo and about 2 % at Sal. The international airport is at Sal and the island houses a developing tourist resort.

The power supply in Cape Verde is based on diesel generator power plants organized in isolated power systems. ELECTRA, the national electric utility company, operates the power systems for Praia, Mindelo and Sal. The total installed diesel generator capacity ranges from about 3 MW at Sal to over 10 MW in both Praia and Mindelo.

ELECTRA is also responsible for desalination of sea water. Based on ELECTRA firm plans and on-going projects, the installed desalination capacity by 1996 is assumed to be 2400 m^3/day for Praia, 6500 m^3/day for Mindelo and 1250 m^3/day for Sal.

ELECTRA's cost of fuels are rather high compared to the world marked prices, partly due to the high costs of handling and storage in Cape Verde. In 1995 ELECTRA paid 19 ECV/l for gas oil, and for heavy fuel, 16500 ECV/ton in Praia and 14000 ECV/ton in Mindelo. At Sal, only gas oil is used. These costs of fuels makes wind power competitive which has been proven by the Step 1 Wind Farms.

The Step 1 Wind Farms included installation of three wind farms - 3x300 kW at Praia, 3x300 kW at Mindelo and 2x300 kW at Sal. The experience and data from the Step 1 Wind Farms forms a reliable background for studying the feasibility of further expansion with wind power.

2.2 Scope of the feasibility study

The FS has explored the feasibility of expanding the wind component of the Cape Verde power systems further than the Step 1 Wind Farms.

The activities of the FS may be summarized as follows:

- Prepare detailed work plan for study.
- Technical power system data acquisition and measurements. Collect all necessary available information on existing power supply systems including grid, diesel generators, transformers etc., in Praia, Sal and Mindelo. Gather supplementary technical information from equipment suppliers on existing equipment and possible new equipment.
- Economic data acquisitions with respect to the power system including performing critical analyses of loads, needs and forecasts for step 2. Select and analyze the most suitable sites and layout for the additional wind turbine units.
- Identify and describe relevant technical alternative solutions for Step 2 system.
- Perform basic control system analysis.
- Steady state analysis of power system in order to identify special requirements to grid and control system design.
- Implement models of power systems and simulate power systems operation for evaluation of system logistics and economics.
- Perform economic and financial analysis of selected alternative system designs.
- Identify and perform analysis of risks connected to step 2.
- Prepare report(s) with Feasibility Study findings and recommendations for further work.

3. Executive summary

Cape Verde has wind energy resources from the trade-winds providing a strong north-easterly flow for most of the year. Wind turbine technology enables extraction of energy from the wind for conversion into electricity. Pilot projects since the early 80'es and a large scale wind farm project which was implemented in 1994 have documented the technical and economic feasibility of wind energy technology for Cape Verde. The three Step 1 Wind Farms were installed in the three main power systems of Cape Verde - Praia, Mindelo and Sal - in which an average of 15% of the electricity consumed is now produced from the wind. Validation of the power system performance model, WINSYS, has been made using the Step 1 Wind Farm operational statistics, which has documented that WINSYS can be used for studying the feasibility of further expansion of wind farms in Cape Verde.

The site selection for possible Step 2 Wind Farms has been made in the light of the experience from Step 1. All data and information valid for the Step 1 Wind Farms are available. The layouts may be made as simple expansions of existing wind farms, although in Mindelo the expansion will have to be located on a neighboring mountain ridge, Selada Flamengo. Uncertainties in wind resource estimates and potential annual wind energy production has thereby been minimized.

The power systems with Step 2 wind farms of varying sizes have been analyzed in terms of operation and performance using the power system performance model WINSYS.

Optimization on cost of energy from wind

The economic optimum installed capacity for each of the three Step 2 Wind Farms is determined as the capacity resulting in the lowest levelized production costs (LPC) of wind energy. The optimum sizes of the Step 2 Wind Farms are achieved for about 1.8 MW wind turbines in Praia, 1.2 MW in Mindelo and 0.6 MW at Sal. Table 2 summarizes assumptions and results for the optimum Step 2 wind farm capacities.

Table 2 Summary of assumptions and results for power system operation with Step 2 Wind Farms

	Praia	Mindelo	Sal
Step 2 wind farm capacity (kW)	1800	1200	600
Potential energy output (MWh/y)	5350	6744	1578
Annual utilized energy (MWh/y)	4777	5863	1446
Wind farm investment (DKK/kW)	5800	5800	5800
Other investments (DKK/kW)	2817	3067	2767
Total investment (DKK/kW)	8617	8867	8567
O&M (% of wind farm investment)	2.5	2.5	2.5
Retrofit cost (% of wind farm invest.)	10	10	10
Salvage value (% of wind farm invest.)	0	0	0
Capacity credit (%)	24	44	18
Annual fuel savings (ton/y)	1046	1331	306
Diesel plant operation time savings (hours/y)	282	1306	82
Levelized production costs (DKK/kWh)	0.40	0.22	0.43

Environmental impact

Whereas the theoretical determination of the external costs are still uncertain, many countries and organizations have decided to put a tax on emission of CO_2, corresponding roughly to 0.10 DKK per kWh of saved electricity from fossil fuel plants, depending on the detailed fuel and power plant specifications.

The Step 2 wind turbines at Cape Verde reduces pollution and CO_2 emission as a consequence of reducing the diesel generators load and fuel consumption. Assuming that saving of one kg heavy fuel corresponds to saving of 3 kg of CO_2, 0.06 kg of SO_2 (assuming fuel with 3 % sulfur weight content) and 0.06 kg of NO_x emissions, and saving of one kg of gas oil corresponds to saving of 3 kg of CO_2, 0.004 kg of SO_2 and 0.06 kg of NO_x emissions, the annual emission savings due to the Step 2 wind farms becomes as shown in Table 3.

Table 3 Estimated annual reduction in CO_2, SO_2 and NO_x emissions due to Step 2 wind farms. For the estimation of emission savings, at Praia and Mindelo the fuel savings is assumed to be heavy fuel only, whereas for Sal the fuel savings are assumed to be gas oil only.

	Praia	Mindelo	Sal
Step 2 wind farm capacity (kW)	1800	1200	600
Annual fuel savings (ton/y)	1046	1331	306
Annual CO_2 savings (ton/y)	3138	3993	918
Annual SO_2 savings (ton/y)	63	80	1
Annual NO_x savings (ton/y)	63	80	18

Economic analysis

The economic analysis assumes the simulation results of the power system operation in terms of utilized energy output, fuel savings, diesel power plant operation time savings and wind power capacity credit. All results related to costs and benefits are given in constant money terms assuming Danish currency (DKK) and the present value time to be 31-Dec-96. All costs are specified assuming price levels of 1995. The discount rate used for the economic analyses is 8 % p.a. in real terms. The economic lifetime is set to 20 years. The technical lifetime of the wind turbines is expected to be the same. The cost-benefit of the wind farm project is assessed in terms of net profit and internal rate of return. Results are shown in Table 4.

Table 4 Summary of assumptions and results for Step 2 wind farm economic cost-benefit analysis. Lifetime is 20 years, discount rate is 8 % p.a. giving an annuity factor equal to 9.82. All costs are discounted to present value.

	Praia	Mindelo	Sal
Step 2 wind farm capacity (kW)	1800	1200	600
Step 2 wind farm costs (kDKK)	18556	12671	6155
Annual utilized energy (MWh/y)	4777	5863	1446
Fuel savings (kDKK)	18514	19340	6695
Non fuel O&M savings (kDKK)	237	1078	53
Capacity credit (kDKK)	1692	2124	422
Net present value (kDKK)	1887	9871	1015
Internal rate of return (%)	9.8	20.5	10.6
External savings (kDKK)	4690	5756	1420
Net present value (kDKK)	6577	15626	2435
Internal rate of return (%)	13.8	27.0	14.1

It appears from the Table 4 that the Step 2 Wind Farms will give an economic benefit. With the exception of results for Praia, the fuel savings alone actually are sufficient for creating a positive result. Taking account for also non fuel O&M savings, capacity credit and externalities, the economic result of the Step 2 Wind Farms becomes very attractive at the given assumptions.

A sensitivity analysis has been performed. It is among other things seen that the levelized production cost is very sensitive to variations in the annual average wind speed, e.g. for Praia, a 10 % lower annual average wind speed would increase the estimated levelized production cost from 0.40 DKK/kWh to 0.52 DKK/kWh. It is therefore essential that uncertainties in the wind resource estimation is low as is the case for the proposed Step 2 Wind Farms.

Conclusions

The Step 2 Wind Farm sizes giving the least cost of energy have been determined to be 1.8 MW at Praia, 1.2 MW at Mindelo and 0.6 MW at Sal. It is the conclusion of the feasibility study that in the major power systems of Cape Verde today wind energy is a technically and economically feasible solution for supply of electricity covering at least up to 25-30% of the consumption.

Implementation of these three wind farms will reduce Cape Verde's dependence on imported fuel oil significantly and contribute to reducing the cost of electricity in the country. Globally, implementation of the Step 2 project will contribute to reducing emissions of greenhouse gasses and the project will serve as a demonstration showing that power systems may be expanded with wind energy up to significant penetration levels without adding expensive control systems and without jeopardizing power system reliability. Due to the lack of international experience with wind energy to these high penetration levels in MW size power systems, the project risks for straight forward commercial investment may seem high for the investor, but the international need for such a demonstration project and the positive experience from the Step 1 Wind Farms should together with the local need for the project make it attractive for funding.

A Draft Project Document has been produced recommending project organization and implementation procedures to be similar to those employed successfully in the Step 1 Wind Farm project, and recommending training and know-how transfer to be emphasized at least at the same level as was the case in the Step 1 Wind Farm project. List of activities, project budget and time schedule are found in the Draft Project Document. The main project risks identified are:

- lack of financial sustainability of ELECTRA (the wind farm owner) to facilitate sustained operation and maintenance
- lack of adequate institutional awareness in ELECTRA and the Cape Verde government
- insufficient human resource development
- large drops in costs of fuel per ton for Cape Verde and ELECTRA, influencing the related savings from wind farm production
- inappropriate power system operation strategies for the combined operation with wind power
- lack of availability of crane for installation and O&M and of adequate transportation for the crane

The probability that the identified project risks will occur is by the feasibility study considered low. Uncertainties are also found to be small in estimates of annual wind energy production and in project outputs and economic results at the proposed project implementation strategy and organization.

4. Crosscutting analysis

4.1 Wind farm siting and layout

Due to the dry climate, large parts of Cape Verde is barren land with little vegetation. Furthermore, the density of habitation is very low outside towns and the few agricultural areas in valleys, mountain slopes or irrigated areas. Praia, Mindelo and Palmeira (Sal) are all surrounded by areas of land offering itself to wind farms with little vegetation and no buildings.

Wind farm sites must be chosen as the most attractive from the evaluation criteria described in Vol. 2, Section 8.1, with the best possible cost-benefit ratio and sufficiently far from the town not to interfere with any possible future town development for at least 20 years.

Such areas of land have already been identified and analyzed in the feasibility study for the Step 1 Wind Farms. At that time the sites were chosen also with a view to the possibilities for future expansion of the wind farms. Site conditions for wind farms have proven favorable at the Step 1 Wind Farms, and land for expansion of the Step 1 Wind Farms is still unoccupied. All in all, availability of suitable land seems not to be the limiting factor for expansion of the wind farm capacities at Praia, Mindelo and Sal.

The question of land ownership seems not yet completely solved, and the possible cost of land is not exactly known for Praia and Mindelo. The status for the Step 1 Wind Farms is stated in Vol. 2, Section 8.1.

The feasibility study strongly recommends that agreements with the municipalities of Praia and S. Vicente are finalized, making necessary reservations and restrictions in use of the land at the wind farms, e.g. in the form of a rental agreement for 25, 50 or 100 years between ELECTRA and the municipality. It should be noted that both the present cattle grazing and operation of the quarry at Praia can be maintained. Land for the possible Step 2 Wind Farms should be included in the agreement. The feasibility study does not include any cost of land in the economic and financial analyses.

The Step 1 Wind Farms have been in operation since December 1994. All data and information valid for the Step 1 Wind Farms are therefore available (see Vol. 2). The site selection for possible Step 2 Wind Farms should be made in the light of this experience from Step 1.

The main advantages of the Step 1 Wind Farm sites are
- favorable, well known and documented wind conditions and wind energy potential
- existing grid interconnections, wind farm monitoring and control systems as well as fiber optic communication from the wind farms to the power stations
- no alternative uses of the land and thus low opportunity costs (price or rent) of land
- little or no present or future obstacles to the wind
- good and known conditions for construction works except for complications due to mountains and wind (complications which have been overcome in Step 1)
- no consequences of noise and no known negative environmental impact from the wind farms
- visual impact already accepted by the local community
- no interference to any planned future development of towns or other physical planning
- low human risks to structural damage or failures of wind turbine (large safety distances)

Expansions at the Step 1 Wind Farms are therefore the obvious solutions. Vol. 2, Section 8 contains a comparison between candidate sites at Praia, Mindelo and Sal, but the conclusion is to recommend Step 2 Wind Farms to be built as expansions of Step 1 Wind Farms to the degree possible. In Mindelo, the Step 2 site - Selada Flamengo - is not exactly an expansion of the Step 1 site, but separated only 1-1.5 km and in very similar conditions and easily connected to the Step 1 site.

4.2 Wind resources

The wind energy resources of Cape Verde have been estimated by several previous studies analyzing data available at that time, e.g. the Wind Energy Assessment Study, UNSO, 1986, and the Wind Farm Project Feasibility Study, DANIDA, 1990. In all cases it has been concluded that the general potential expressed in terms of the annual average wind speed 10 m above ground level at sea level elevation in flat open smooth terrain, like grass or sand, is approximately 7 m/s.

The feasibility study recommends to use the actual wind data measured in 1995 at the Step 1 Wind Farms to generate the wind speed probability density distributions for wind energy production estimation for the Step 2 Wind Farms at the selected wind farm sites. Table 5 gives the resulting values of estimated annual average wind energy resources at 30 m height above ground level (agl) in terms of the annual average wind speeds U_{mean} and the Weibull probability density distribution scale and shape parameters (A, k).

Table 5 Estimated wind energy resources at a height of 30 m agl - annual average wind speed (U_{mean}) and Weibull scale and shape parameters (A, k).

	U_{mean} (m/s)	Weibull - A (m/s)	Weibull - k
Praia - Mt. S. Filipe	7.8	8.9	3.62
Mindelo - Selada Flamengo	10.4	11.7	4.02
Sal - Palmeira	7.4	8.3	3.62

As input to the power system modeling, seasonal and diurnal variations of wind speeds have been determined.

4.3 Wind turbine technology

The type and size of the wind turbines of the Step 1 Wind Farms has proven appropriate with respect to transportation, erection and operation.

The wind turbines for Step 2 wind farms should be based on and of similar quality as an approved type in accordance with the Danish regulations and requirements, i.e. class A or B Danish Type Approval for operation in the local climatic conditions at the wind farm sites in Cape Verde and for operation in the local power systems at which they are to be installed.

Recommendations regarding wind farm equipment design and installation based on the experience from Step 1 are given in Vol. 2, Section 8.5 and 9.1.

4.4 Power system development plans and forecasts

Two different development scenarios for the power sector regarding consumer loads, grid connected desalination plants and diesel power plants capacity have been assumed by the FS.

The two scenarios for the development within the analysis period of 20 years can briefly be defined as follows:

- Scenario A:
  A scenario assuming continued economic growth, which for Mindelo and Sal is determined in accordance with the Master Plan (prepared in cooperation with the World Bank) - except for minor agreed upon modifications, and which for Praia is adjusted relative to the Master Plan in accordance with the newer EDF study "scenario 1" suggestions for Praia.
- Scenario B:
  A scenario originally recommended by the DANIDA Project Review, September 1994, aiming at a conservative determination of the amount of wind power capacity to be installed in a Step 2. This scenario assumes a development in consumer loads identical to that of Scenario A except for the desalination loads. The desalination capacity and loads assumed is in this scenario limited to the amount installed by the first year of operation of the Step 2 Wind Farms (1998) for which firm plans exist. The development in diesel power plant capacity is reduced correspondingly, due to the reduced needs for diesel capacity according to this scenario.

Vol. 2, section 7 give further details on the assumed development scenarios in terms of annual consumer loads, grid connected desalination plants and diesel capacity.

4.5 Technical power system analysis

4.5.1 Power quality assessment - experience from Step 1 Wind Farms

During the FS three measurement campaigns for each of the power systems have been performed together with ELECTRA, i.e. one campaign prior to the installation of the wind farms, one campaign during commissioning and one after. The campaigns are described in detail in Summary of Discussions Dec. 93, Nov. 94 and May 95. Analyses of the measurements have been prepared giving the following indications:

- The Step 1 wind turbines do not have a severe impact on the steady state voltage and frequency. The measured steady state voltage and frequency are well within the normally adopted international standards, e.g. CENELEC EN50160.
- Severe voltage unbalances have been observed in both Praia, Mindelo and Sal in Nov. 94. The voltage unbalance is not caused by the Step 1 wind turbines, but may if not kept below an acceptable low level force the wind turbines out of operation. In May 95, the voltage unbalances were within acceptable limits for Mindelo and Sal, whereas for Praia the voltage unbalance was exceeding 2 %, i.e. the maximum allowable level according to CENELEC EN50160. ELECTRA will take action as to reduce the voltage unbalance in Praia.
- The Step 1 wind turbines reduce the power factor at the diesel power plant as the wind turbines produce active power and consume reactive power. This leaves the diesel power plant at a lower active load and a higher reactive load than it would have been without the wind power in the system. As long as sufficient spinning capacity is maintained for supplying the needed active and reactive power, the reduced power factor operation will not introduce any critical conditions.
- The Step 1 wind turbines produce a variable output power which superimposes load fluctuations on the diesel power plant. The fluctuations cause increased governor operation as to maintain a close to constant grid frequency. Severe fluctuations are not observed, and according to communication with the diesel engine manufacturer,

MAK, the observed fluctuations will not have an impact on the wear of the diesel engines or the fuel consumption.

The measurements are further described in Vol. 2, Section 4.1.

4.5.2 Electrical grid design

Scope of analysis

With the purpose of investigating the steady state impact on the ELECTRA power systems of Sal, Mindelo and Praia when introducing the wind turbines of the Step 1 wind farms and the additional wind turbines of the possible Step 2 extensions of the wind farms, Load Flow analysis has been performed. The specific objectives of the Load Flow analysis is recommendations on possible grid reinforcements and wind farm grid connections, possible allocation and sizing of capacitor banks, possible constraints on the operational strategy of each grid and finally to check each grid for possible steady state voltage problems in selected worst cases.

It should be noted that on these island power system capabilities with a high wind penetration, a dynamic and transient stability analysis has to be accomplished. Analyses which are not part of the terms of reference for the feasibility study, but postponed to be performed in a later phase for the actual project proposed by the present feasibility study.

Findings and recommendations

In the three ELECTRA grids no critical high or low voltages have been detected in any of the selected worst cases analyzed.

The voltage rise across the (long) wind farm grid connection cables is fully acceptable in all cases on all three islands.

The power losses in the wind farm grid connection cables is fully acceptable in all cases on all three islands.

No capacitor banks should be installed only with the purpose of compensating the full-load reactive power demand of the wind turbine generators. This is provided by the production of capacitive reactive power by the wind farm grid connection underground cables themselves in all cases in each of the Sal, Mindelo and Praia grids.

Due to the rapid growth of the electrical grid in Praia and Mindelo, and due to the planned new power station in Praia, capacitor banks have been included in the Load Flow analysis on these grids. In Praia the capacitor bank (-1600 kVAr) is assumed connected to the old power station high voltage busbar (15 kV) providing voltage support in high load situations as the total power production is assumed supplied solely from the new power station and the wind farm. In Mindelo the capacitor bank (-2000 kVAr) is likewise assumed connected to the power station high voltage busbar (6.3 kV) providing voltage support in high load situations mainly as the grid is assumed operated at its present voltage level of 6.3 kV. When upgrading to a system voltage to 20 kV, as planned in the future, the present low voltage problems will most likely be eliminated. On these grounds the high voltage capacitor banks are not included in the final project budget for electrical grid equipment.

The grid power factor is maintained or even improved in each grid when introducing the wind turbines and grid connections of the Step 1 wind farms and the possible extensions of Step 2.

It can generally be concluded, that none of the Sal, Mindelo and Praia grids, in the assumed state of 1998, has shown problems in absorbing neither the wind turbines and grid connections of the Step 1 wind farms nor the possible Step 2 wind farm extensions in terms of steady state power flow.

It is recommended, that an electrical grid study concerning the necessity of installing capacitor banks in Praia and Mindelo should be conducted. Especially in the Praia grid when introducing the planned new power station. This study should comprise sizing and location of the capacitor banks as well as operational strategies for controlling each capacitor bank level of compensation.

A full dynamic and transient stability analysis must be conducted prior to *any* expansion of the Step 1 wind farms.

4.5.3 Power system operation

The power systems with and without the Step 2 wind farms has been analyzed in terms of operation and performance using the power system performance model WINSYS. WINSYS is described in Vol. 2, annex H. Table 6 summarizes results. Detailed results and assumptions are found in Vol. 2, section 11 and 12 and Vol. 2, annex I, J and K for Praia, Mindelo and Sal respectively.

Table 6 Summary assumptions and results for power system operation with Step 2 wind farm.

	Praia		Mindelo		Sal	
Step 2 wind farm capacity (kW)	1800		1200		600	
Scenario	A	B	A	B	A	B
Potential energy output (MWh/y)	5350	5350	6744	6744	1578	1578
Annual utilized energy (MWh/y)	4777	4774	5863	5679	1446	1426
Capacity credit (%)	24	24	44	44	18	18
Annual fuel savings (ton/y)	1046	1045	1331	1283	306	300
Diesel plant operation time savings (hours/y)	282	229	1306	1095	82	18

4.6 Environmental impact

It is accepted that electricity production from fossil fuels causing pollution and emission of greenhouse gasses (CO_2) imposes external costs. Whereas the theoretical determination of the external costs are still uncertain, many countries and organizations have decided to put a tax on emission of CO_2.

In Denmark, the Government has put a CO_2 tax on fossil fuel based electricity production at 0.10 DKK/kWh. In the future, there may be an international agreement to put tax on world market fuels as to internalize the external costs connected with combustion of fossil fuels. Presently, international funding agencies pay increasing attention to the environmental impact of any project considered for support. Most notably, the World Bank GEF (Global Environmental Facility) offers grants of up to 20 USD per ton saved CO_2. Depending on the detailed fuel and power plant specifications, this corresponds roughly to 0.10 DKK per kWh of saved electricity from fossil fuel plants.

The Step 2 wind turbines at Cape Verde reduces pollution and CO_2 emission as a consequence of reducing the diesel generators load and fuel consumption. Assuming that saving of one kg heavy fuel corresponds to saving of 3 kg of CO_2, 0.06 kg of SO_2 (assuming fuel with 3 % sulfur weight content) and 0.06 kg of NO_x emissions, and saving of one kg of gas oil corresponds to saving of 3 kg of CO_2, 0.004 kg of SO_2 and 0.06 kg of NO_x emissions, the annual emission savings due to the Step 2 wind farms becomes as shown in Table 7. The emission factors above are from CORE Environmental Data Base by SEI/UNEP. The actual emission factors may differ from the above depending on the actual diesel generator specifications and operation as well as on the fuel quality. In particular, the emission of NO_x is heavily dependent on the actual combustion system of the specific diesel generator. The above 0.06 kg of NO_x emissions per kg fuel consumed is assumed to be in the low range for the present diesel generators in Cape Verde. As an average number taking account also for the future development, the 0.06 kg is considered realistic as new diesel generators may be equipped with NO_x emission control, limiting the emission to about 10 g/kWh or 0.05 kg per kg fuel consumed. (The 10 g/kWh is according to information from the diesel engine manufacturer MAK.)

Table 7 Estimated annual reduction in CO_2, SO_2 and NO_x emissions due to Step 2 wind farms. For the estimation of emission savings, at Praia and Mindelo the fuel savings is assumed to be heavy fuel only, whereas for Sal the fuel savings are assumed to be gas oil only.

	Praia		Mindelo		Sal	
Step 2 wind farm capacity (kW)	1800		1200		600	
Scenario	A	B	A	B	A	B
Annual fuel savings (ton/y)	1046	1045	1331	1283	306	300
Annual CO_2 savings (ton/y)	3138	3135	3993	3849	918	900
Annual SO_2 savings (ton/y)	63	63	80	77	1	1
Annual NO_x savings (ton/y)	63	63	80	77	18	18

4.7 Economic and financial analysis

The economic and financial analyses assume the simulation results of the power system operation in terms of wind farms utilized energy output, fuel savings, diesel power plant operation time savings and wind power capacity credit. The power system operation simulations are all made using conservative assumptions leading to also conservative results. In particular, the wind turbines energy output is calculated assuming wind turbine performance as for the Step 1 wind turbines, and not as newer designs with better cost efficiency. Another conservative assumption is that the specific fuel consumption of the diesel engines is assumed to remain constant during their lifetime, whereas in reality, the fuel efficiency of a diesel generating set is known to be reduced over time due to machinery wear. Taking this into consideration, the estimated fuel savings due to the wind farms energy output would become higher, and the economic and financial results would become more favorable for the Step 2 wind farms.

4.7.1 Economic analysis

The economic analyses consider the costs and benefits of the Step 2 wind farms project for Cape Verde. All results related to costs and benefits are given in constant money terms assuming Danish currency (DKK) and the present value time to be 31 Dec. 1996. All costs are specified assuming the price level of 1995. The following exchange rates are assumed:

8 000 ECV for 100 USD
650 DKK for 100 USD
1231 ECV for 100 DKK

The discount rate used for the economic analyses is 8 % p.a. in real terms.

The economic lifetime is set to 20 years. The technical lifetime of the wind turbines is expected to be the same.

Costs and benefits are calculated for the two development scenarios defined in section 4.4.

The economic optimum number of Step 2 wind turbines in each of the wind farms are determined as the number resulting in the lowest wind energy costs at scenario A assumptions.

The cost of the Step 2 wind farms energy output is estimated for each of the assessed sites, i.e. Praia, Mindelo and Sal, as the levelized production cost following the recommended practices as described by IEA expert group study. The levelized production cost (LPC) is the cost of one production unit (kWh) averaged over the wind farm's entire expected lifetime.

At further detailed assumptions and analysis results as reported in Vol. 2, Section 13.1, the economic optimum size of the step 2 wind farms are achieved for about six 300 kW Step 2 wind turbines in Praia, four in Mindelo and two at Sal. Table 8 summarizes assumptions and results for the optimum Step 2 wind farm capacities at both scenario A and B assumptions.

The cost-benefit of the wind farm project is assessed in terms of net profit and internal rate of return.

Table 8 Summary assumptions and results for Step 2 wind farm cost of energy estimate. Retrofit is assumed after 10 years of operation. Lifetime is 20 years, discount rate is 8 % p.a. giving an annuity factor equal to 9.82.

	Praia		Mindelo		Sal	
Step 2 wind farm capacity (kW)	1800		1200		600	
Wind farm investment (DKK/kW)	5800		5800		5800	
Other investments (DKK/kW)	2817		3067		2767	
Total investment (DKK/kW)	8617		8867		8567	
O&M (% of wind farm investment)	2.5		2.5		2.5	
Retrofit cost (% of wind farm invest.)	10		10		10	
Salvage value (% of wind farm invest.)	0		0		0	
Scenario	A	B	A	B	A	B
Annual utilized energy (MWh/y)	4777	4774	5863	5679	1446	1426
Levelized production costs (DKK/kWh)	0.40	0.40	0.22	0.23	0.43	0.44

The net profit (NPV) of the investment is calculated for the assessed wind farms of Praia, Mindelo and Sal, as the discounted difference between annual savings and costs over the assumed economic lifetime of the wind farms. The savings considered are related to:

- diesel power plant fuel costs,
- diesel power plant non fuel variable operation and maintenance costs,
- costs of emission of greenhouse gasses (CO_2 emissions due to diesel power plant generation of electric power),
- wind power capacity credit.

The internal rate of return (IRR) of the investment is estimated for each of the assessed wind farms as the discount rate corresponding to NPV = 0.

Based on the detailed assumptions and analysis results as reported in Vol.2, Section 13.2, Table 9 summarizes the present value costs and savings for scenario A and B with and without external costs. It appears from the table that the Step 2 wind turbines will give an economic benefit for both scenarios. With the exception of results for Praia, the fuel savings alone actually are sufficient for creating a positive result. Taking account for also non fuel O&M savings, capacity credit and externalities, the economic result of the Step 2 wind farms becomes very attractive.

Table 9 Summary assumptions and results for Step 2 wind farm economic cost-benefit analysis. Lifetime is 20 years, discount rate is 8 % p.a. giving an annuity factor equal to 9.82. All costs are discounted to present value.

	Praia		Mindelo		Sal	
Step 2 wind farm capacity (kW)	1800		1200		600	
Step 2 wind farm costs (kDKK)	18556		12671		6155	
Scenario	A	B	A	B	A	B
Annual utilized energy (MWh/y)	4777	4774	5863	5679	1446	1426
Fuel savings (kDKK)	18514	18491	19340	18660	6695	6585
Non fuel O&M savings (kDKK)	237	187	1078	903	53	12
Capacity credit (kDKK)	1692	1692	2124	2124	422	422
Net present value (kDKK)	1887	1814	9871	9016	1015	864
Internal rate of return (%)	9.8	9.7	20.5	19.4	10.6	10.3
External savings (kDKK)	4690	4687	5756	5576	1420	1400
Net present value (kDKK)	6577	6501	15626	14591	2435	2264
Internal rate of return (%)	13.8	13.8	27.0	25.7	14.1	13.7

Assuming six 300 kW wind turbines in Praia, four in Mindelo and two at Sal, the LPC, NPV and IRR is calculated using WINSYS for a range of variations around scenario A assumptions and neglecting external costs. Vol. 2, figs. 13.6 - 13.8 show the levelized production cost sensitivity to changes in the assumptions. It is seen that the levelized production cost is very sensitive to variations in the annual average wind speed, e.g. for Praia, a 10 % lower annual average wind speed would increase the estimated levelized production cost from 0.40 DKK/kWh to 0.52 DKK/kWh. Vol. 2, figs. 13.11 - 13.13 and 13.14 - 13.16 show the NPV and IRR sensitivity to changes in the assumptions. It is seen that both the NPV and the IRR are very sensitive to variations in the annual average wind speed.

The results are also sensitive to the assumed relation between present value time, and timing of investment and benefits. The calculations assume a present value time of end 96, and that the investment is made end 96 just before the Step 2 wind turbines start operation, and operation is credited at the end of each year thereafter. Assuming instead that the present value time is mid 96, and that the investment is made end 96 just before the Step 2 wind turbines start operation, and operation is credited mid each year, the investment should be discounted to present value (i.e. reduced with 4 % assuming an annual discount rate of 8 %) resulting in less present value costs and more attractive results.

4.7.2 Financial analysis

The financial analyses consider the costs and benefits of the Step 2 wind farms project for ELECTRA. The assumptions for the financial analyses are as for the economic analyses except for fuel and external costs. External costs are not applicable for the financial analysis.

In the financial analysis, the fuel costs are assumed to be the price as paid by ELECTRA which is different from the actual cost of fuel to the Cape Verde society due to subsidy. The 1995 heavy fuel prices for ELECTRA are assumed to be 14.0 ECV/kg of heavy fuel at Mindelo and 16.5 ECV/kg at Praia. At Sal gas-oil only is used. The 1995 price of gas-oil for ELECTRA is assumed to be 19.0 ECV/l. The world market fuel prices for ELECTRA are assumed to increase with 1.5 % p.a. during the analysis period. Comparing the forecasted fuel prices as they appear to ELECTRA with the forecasted fuel costs as they appear to the Cape Verde society in Vol. 2, section 13, it is seen that the fuel subsidizes paid by the Cape Verde government are assumed to be reduced, narrowing the gap between the actual fuel costs and the price paid by ELECTRA.

The financial analysis does not consider impact on different options for financing the project, nor does it consider possible additional project costs for monitoring of project performance, dissemination of project results and other additional costs due to the particular nature of the project. This leads to that the investment costs considered for this financial analysis are as for the economic analysis, and the financial costs of wind energy become equal to the economic costs of wind energy.

Tables 10 and 11 summarize the results of the financial analysis. It is noted that the financial net present values and internal rate of return's become less than the corresponding economic values as the value of the fuel savings due to subsidy are less for ELECTRA than for the Cape Verde society. Taking into consideration that fuel subsidies may not be the best way for the Cape Verde government to support ELECTRA in keeping electricity and water sales prices below certain tariffs, fuel subsidies may be taken away, making the financial analysis results for the Step 2 wind farms as favorable as the economic analysis results. Further, it is

Table 10 Summary assumptions and results for Step 2 wind farm financial cost-benefit analysis. Lifetime is 20 years, discount rate is 8 % p.a. giving an annuity factor equal to 9.82. All costs are discounted to present value.

	Praia		Mindelo		Sal	
Step 2 wind farm capacity (kW)	1800		1200		600	
Step 2 wind farm costs (kDKK)	18556		12671		6155	
Scenario	A	B	A	B	A	B
Annual utilized energy (MWh/y)	4777	4774	5863	5679	1446	1426
Levelized production cost (DKK/kWh)	0.40	0.40	0.22	0.23	0.43	0.44
Fuel savings (kDKK)	15808	15786	17140	16548	6350	6246
Non fuel O&M savings (kDKK)	237	187	1078	903	53	12
Capacity credit (kDKK)	1692	1692	2124	2124	422	422
Net present value (kDKK)	-819	-891	7670	6904	670	525
Internal rate of return (%)	7.2	7.2	17.6	16.6	9.7	9.4

Table 11 Summary assumptions and results for Step 2 wind farm financial cost-benefit analysis assuming investments to include spare parts for initial period of operation. Lifetime is 20 years, discount rate is 8 % p.a. giving an annuity factor equal to 9.82. All costs are discounted to present value.

	Praia		Mindelo		Sal	
Step 2 wind farm capacity (kW)	1800		1200		600	
Step 2 wind farm total costs (kDKK)	18363		12542		6091	
Scenario	A	B	A	B	A	B
Annual utilized energy (MWh/y)	4777	4774	5863	5679	1446	1426
Levelized production cost (DKK/kWh)	0.39	0.39	0.22	0.22	0.43	0.43
Fuel savings (kDKK)	15808	15786	17140	16548	6350	6246
Non fuel O&M savings (kDKK)	237	187	1078	903	53	12
Capacity credit (kDKK)	2538	2538	3186	3186	634	634
Net present value (kDKK)	221	148	8826	8095	946	800
Internal rate of return (%)	8.2	8.1	20.4	19.4	10.5	10.2

emphasized that the analyses are performed using conservative assumptions. Actually, changing the assumed wind turbines O&M down from 2.5 % p.a. to 0.5 % p.a. during the first year of operation as to reflect the fact that the assumed investment includes spares for this period, and changing the capacity credit up from 4000 DKK/kW to 6000 DKK/kW as to include also the displaced diesel capacity maintenance savings, the financial results with the subsidized fuel prices change from those in table 10 to the more attractive results shown in table 11. Finally, the actual financial result for ELECTRA will indeed depend on the funding agreement and conditions.

4.7.3 Economic and financial analysis with modified assumptions

As a response to ELECTRA recommendations in fax of 030696, see Vol. 2, App. P, the economic and financial analyses have been performed with certain assumptions modified relative to those assumed in section 4.7.1 and 4.7.2. The detailed calculation assumptions and results are given in Vol. 2, App. Q. The modified assumptions are summarized as follows:

- The assumed fuel cost development is modified relating to the Electricity Master Plan assumptions so that the economic and financial cost of heavy fuel reaches 35 USD in year 2010 in Mindelo. The fuel costs of 1995 are assumed to be as in section 4.7.1 and 4.7.2. The costs of fuel assumed in Praia and at Sal after 1995 are modified as to follow the same percentage increment as assumed for Mindelo.
- The economic and financial lifetime assumed is reduced from 20 to 15 years.
- The capacity credit is reduced from 24, 44 and 18 % of rated Step 2 wind turbine capacity for Praia, Mindelo and Sal to 4, 6 and 5 % respectively. It is emphasized that the capacity credits of 24, 44 and 18% are estimated applying the best available data and state of the art methodology using the loss of load approach. See also Vol. 2, Sec. 11 and Vol. 2, App. O.
- Currency exchange rates are kept constant throughout the analysis period applying constant money terms as also applied in section 4.7.1 and 4.7.2.

The results of the economic and financial analysis using the modified assumptions are summarized in Table 12 and Table 13 below.

Table 13 Summary assumptions and results for Step 2 wind farm financial cost-benefit analysis with modified assumptions. Lifetime is 15 years, discount rate is 8 % p.a. giving an annuity factor equal to 8.56. All costs are discounted to present value.

	Praia		Mindelo		Sal	
Step 2 wind farm capacity (kW)	1800		1200		600	
Step 2 wind farm total costs (kDKK)	18228		12452		6046	
Scenario	A	B	A	B	A	B
Annual utilized energy (MWh/y)	4762	4758	5820	5615	1443	1420
Levelized production cost (DKK/kWh)	0.45	0.45	0.25	0.26	0.49	0.50
Fuel savings (kDKK)	13910	13903	14956	14413	5034	4945
Non fuel O&M savings (kDKK)	217	177	926	837	28	4
Capacity credit (kDKK)	282	282	290	290	117	117
Net present value (kDKK)	-3818	-3865	3719	3087	-866	-980
Internal rate of return (%)	3.8	3.7	13.1	12.2	5.1	4.7

Table 12 Summary assumptions and results for Step 2 wind farm economic cost-benefit analysis with modified assumptions. Lifetime is 15 years, discount rate is 8 % p.a. giving an annuity factor equal to 8.56. All costs are discounted to present value.

	Praia		Mindelo		Sal	
Step 2 wind farm capacity (kW)	1800		1200		600	
Step 2 wind farm costs (kDKK)	18228		12452		6046	
Scenario	A	B	A	B	A	B
Annual utilized energy (MWh/y)	4762	4758	5820	5615	1443	1420
Levelized production costs (DKK/kWh)	0.45	0.45	0.25	0.26	0.49	0.50
Fuel savings (kDKK)	15979	15972	16381	15771	5605	5506
Non fuel O&M savings (kDKK)	217	177	926	837	28	4
Capacity credit (kDKK)	282	282	290	290	117	117
Net present value (kDKK)	-1750	-1797	5145	4446	-295	-419
Internal rate of return (%)	6.1	6.0	15.1	14.1	7.0	6.6
External savings (kDKK)	4076	4073	4982	4806	1235	1216
Net present value (kDKK)	2326	2276	10126	9252	940	797
Internal rate of return (%)	10.4	10.4	21.2	20.0	10.9	10.5

4.8 Organizational and institutional aspects

The institutional analysis is focused on ELECTRA, the national power company responsible for electricity and water from planning, design and construction of plants to purchase of fuels, operation of plants, production and distribution to consumers.

ELECTRA is a public company with its head quarters in Mindelo, with subsidiaries (Delegations) in Praia, S. Vicente and Sal, responsible for the operation locally, including wind farms.

The Step 1 Wind Farm project was implemented by ELECTRA and it is assumed that a Step 2 Wind Farm project would be so too.

Restructuring of ELECTRA

Restructuring of ELECTRA has been discussed for some years and several models for the future structure of the supply of electricity and water have been set up ranging from one single company - state owned or fully privatized - covering all islands to a fully "atomized" supply system with every municipality taking care of the local supply, maybe through a contractor, ELECTRA.

The scenarios which have been formulated regarding the future structure of the energy supply will of course also influence the operation of the wind farms. The burden of capital costs of all existing machinery etc. combined with regulated tariffs for electricity and water depends on the structure which is chosen. Presently, the tariffs do not allow for generating a turnover sufficient to support the operation costs. It may be suggested that some of the assets are written off in order to improve the financial state.

ELECTRA has received the Step 1 Wind Farms on on-lending terms from the Government, and - depending on the future status of ELECTRA and of the ownership of the wind farms - the pay back terms will influence the future operation, maintenance, training, etc., through the budget.

It is expected that the Step 2 Wind Farms are to be part of the power station unit responsible for producing electricity. Reorganization or privatization of ELECTRA will not in itself remove the encouragement to perform proper operation and maintenance of the wind farms. On the contrary, once the investment has been made, the more electricity generated from the wind farms the higher the savings at the power stations, which is an incentive for keeping the wind farms operating in any organization, not the least a privatized company.

Responsibilities and awareness in ELECTRA - Engineering and Technical Departments

The responsibility and management of all planning and project implementation of wind farm projects are with the Engineering Department of ELECTRA. After Taking-Over, the responsibility of operation and maintenance of the wind farms is transferred to the Technical Department and local ELECTRA Delegations. By the time of the suggested implementation of a Step 2 Wind Farm project, the organization will have 2-3 years of experience from implementation and operation of Step 1.

The awareness in ELECTRA of the Step 1 Wind Farms seems to vary from island to island. It seems that the higher the wind energy penetration - contribution from wind energy to electricity consumption - the more attention the integration of the wind farms is given. Step 2 will increase the wind energy penetration and thus it may be expected that the awareness of the organization and the status of the organizational body and staff responsible will increase as well.

Co-production of water and electricity

A special item to consider is the co-production of water and power. According to the production method, the two products are coupled in the manufacturing process, but are sold at prices which do not reflect the production costs. At present, the water is sold far below production costs. This means that the overall budget must allocate resources for the water production which may be taken from the power production, e.g. from the wind farm budgets. It is evident that financial transparency as well as ELECTRA management and government awareness of the necessity of operation and maintenance budgets for wind farms must be developed. Establishing of separate accounts and budgets for wind farms have been initiated.

Project Implementation

In accordance with ELECTRA and the Project Steering Committee preferences, it is recommended that the project implementation methodology and thus organizational setup, type of consultancy services and contractors as well as the activities involved in principle should be similar to what has been applied in the implementation of the Step 1 Wind Farm project. However, prior to a Step 2 funding commitment, documentation of the power system dynamic and transient stability with the proposed Step 2 Wind Farms should be established. The necessary study could be carried out in parallel with or as an integral part of a project appraisal.

4.9 Sociological

The Step 2 wind farms will reduce costs of electricity generation in Praia, Mindelo and Sal. The availability of electricity at reasonable cost and adequate quality is a help for increasing the standard of living at all levels in the Cape Verdean society. The Step 2 wind farm project will also have a positive effect on the availability of desalinated water at a reasonable cost, since large scale desalination of sea-water is crucial for Cape Verde, and since the desalination is a major consumer of electricity. In total the Step 2 wind farms help solving some of the core development problems of Cape Verde.

4.10 Uncertainties and risks

The main sources of economic and financial uncertainties and risks identified are listed and commented upon below:

Project costs and lifetime

The project costs are the investments and O&M costs. The estimated project investment costs are based on actual contract prices for Step 1, and the uncertainty of the estimates is considered to be low.

The wind farms O&M costs estimate is slightly higher than commonly assumed for newer wind farms in Denmark. Actual experience for O&M costs of wind farms in Cape Verde is not presently available, making the O&M cost estimate somewhat more uncertain than the investment cost estimate.

The lifetime of the wind turbines is estimated assuming the wind turbines to live up to their design specifications, i.e. wind turbines with a Danish type approval (or similar) are designed for a lifetime of 20 years. Assuming wind turbines of proper quality are selected for the project, and that these are maintained during their lifetime, the uncertainty of the estimated lifetime is considered to be low.

The economic sensitivity to changes in any of the above parameters are quantified in Vol. 2, section 13. It is seen that even dramatic changes of +/- 20 % of any of the above parameters have limited impact on the economic results.

Wind turbines energy output

The wind turbines energy output is estimated from a set of analyses and assumptions as specified in Vol. 2, sections 8 and 12. The economic sensitivity to changes in any of the assumed parameters are quantified in Vol. 2, section 13. It is seen that the results are most sensitive to changes in the estimated average wind speed at the wind turbines hub-height, whereas other parameters such as e.g. the assumed electric consumer load development have limited impact only. In total, as further discussed below, the uncertainties of the annual wind energy production estimates are considered low due to the site selection made and the documented performance of the Step 1 Wind Farms.

Wind energy resource estimates:

- The uncertainties of annual wind energy production estimates are considered low due to the site selection made and the documented performance of the Step 1 Wind Farms.
- As can be seen from long-term climatological records from Sal airport, inter-annual variations exist, which means that the energy production will vary from year to year due to climatological variations. The estimates presented are the expected average values for a 10-year period.
- Furthermore, as to minimize uncertainty of the wind resource assessment for the Step 2 Wind Farm at Mindelo, wind measurements on the Step 2 site (Selada Flamengo) are in progress. Comparisons of data from these measurements for a first 10 days of measurements to data from the Step 1 site seem to confirm that the assumption made based on modeling is quite accurate. These wind measurements should continue preferably for a complete year.

Wind turbine technology and technical availability:

- The wind energy production estimates are based on the Step 1 experience regarding power performance, technical availability of wind turbines and technical availability of the electric grids. It is stressed that the wind turbines must be of adequate quality with a proven record of operation and power performance. To minimize risks, it is recommended that wind turbines are approved in accordance with the Danish type approval requirements or similar (see Vol. 2, section 8.5).
- Loss of communication between power station and wind farm influence power system operation with Step 2 wind farms may lead to reduced utilized wind energy production. Manual operation is however possible, and the losses may be minimized by applying manual shut-down and start-up procedures through radio communication with wind farm operators on-site.
- The wind turbine manufacturer should be consulted on setting up an economically viable strategy for spare parts procurements and management limiting the outage-time of the wind turbines and reducing the investments in spare parts to the degree possible.
- Access to the only large crane in Cape Verde capable of erecting up to 300 kW wind turbines is essential. The crane was supplied to ELECTRA as part of the Step 1 Wind Farm project, on the condition that the crane will be available for the wind farm projects whenever and wherever needed. To minimize risks, it is recommended to include equipment for lifting spare parts to the nacelle as part of the Step 2 wind turbines - the options in terms of size and cost should be specified by the manufacturers in their tenders.

Combined power supply system operation:

- It is important to develop power system operation strategies and tools, considering wind and load fluctuations, operational constraints of diesel generating sets, and total power system fuel efficiency. Wind turbine capacity can be shut-down by the operators in periods with low consumption (nights) and high wind speeds. The losses due to these shut-downs should be minimized. An operational strategy should be proposed by the project and tools for assisting the operators should be developed and provided as part of the wind farm equipment for installation as remote facilities for the operators in the diesel power stations. The operation should be manual and the remote facilities to be supplied should be assisting this manual operation.
- The proposed Step 2 Wind Farm project will reach a wind energy penetration of approximately 25%. The staff responsible on all levels for Cape Verde's electricity supply will need to be fully informed and confident that the technology can be handled in the power system. The completely manually based power system operation is chosen in order to facilitate the necessary know-how build up and transfer in ELECTRA. Training courses for planners, managers, engineers and operators particularly regarding combined power system operation and wind power's integration in conventional power systems will be crucial for optimal exploitation of wind energy in Cape Verde.
- It is pointed out by the feasibility study that sizes of new diesels generating units to be procured should be decided taking the total power system cost efficiency and operation, including wind farms, into consideration.
- Uncertainties in load forecasts may introduce an uncertainty in the estimate of the utilized wind energy production. Less load than forecasted means increased dissipation of the wind power production. The load depends on a number of assumptions such as: economic growth, development in population, development in the use of electrical devices, development of industry and grid expansion. Reference is again made to the sensitivity analyses of Volume 2, showing that the sensitivity is low.

Value of savings due to wind farms energy output

The estimated value of savings due to the wind farms energy output depends on the value of diesel power plant operation savings, the wind farms capacity credit and savings of externalities. As can be seen from Vol. 2, Section 13, the economic sensitivity to changes in the fuel savings is higher than the sensitivity to changes in non fuel O&M savings or capacity credit.

The uncertainty of the estimated fuel savings in terms of tons of fuel are low as based on detailed power system simulations using the simulation model WINSYS proven to accurately estimate measured fuel consumption and wind energy production during a 6 months period with Step 1 wind farms operation. If the prices of fuel are increasing during the lifetime of the wind turbines, the economic gains from investment in wind turbines also increase and vice versa. The estimated development of the fuel prices during the lifetime of the turbines is the "best guess" for the time being, but the expectations to the future development may change very quickly. For the time being the price of fuel is very low compared to prices during the last ten to fifteen years. The most likely estimate is for prices to increase in real terms during the coming years. Such development requires certain political events to happen and if they do not occur the price may stay low or even decrease.

The uncertainty of the assumed external savings is high, i.e. the savings might be both much higher than the assumed 0.10 DKK/kWh or they may be almost negligible. There is however no project risk connected to the uncertainty of the external savings as the project is economically favorable even at the unrealistic assumption of neglecting the external savings.

Financing of wind farms investment and O&M costs

Taking the general financial situation of ELECTRA into consideration, it is noted that the present price structure for electricity and water in connection with the fuel prices (all fixed by the Government) determines the financial resources for ELECTRA and therefore also for the wind farms.

The financial analyses for the Step 2 wind farms give approximately 20 % internal rate of return for the Mindelo wind farm assuming a 20 years pay-back period, whereas for Praia and Sal the corresponding values are around 8 and 10 % respectively. Assuming the investments to be financed through a soft loan to ELECTRA over the 20 years lifetime of the wind farms and with a real discount rate of e.g. 2 % p.a., the large margins to the financial internal rates of returns indicate low financial risks and a high possibility for ELECTRA being able to pay back the loan and still gain a profit of the wind farms.

The financial analyses for the Step 2 wind farms give the above high internal rates of returns at the assumption that the wind turbines are proper maintained during their lifetime at an annual cost of 2.5 % of the investment. In addition, a major overhaul after 10 years of operation is included at a cost of 10 % of the investment. The assumed O&M costs are average costs. In reality, the O&M costs will vary from year to year, and it is thus important that ELECTRA sets aside the necessary funds. Considering the high internal rate of returns, risks are low in connection with allocation of funds within ELECTRA for financing the O&M of the wind farms.

5. Proposal/recommendations

Prior to deciding to install the proposed Step 2 wind farms, it is recommended to perform a dynamic and transient power system analysis as to ensure that the power systems of Praia, Mindelo and Sal remain dynamically stable.

Wind turbines

Step 2 wind farms are proposed as extensions of the Step 1 wind farms. The proposed Step 2 wind farms are 1800 kW of wind turbine capacity at Praia, 1200 kW at Mindelo and 600 kW at Sal.

The wind turbines may not necessarily have to be Nordtank 300 kW, but could be any size that could be erected by the use of the available crane procured by Step 1 or any other crane permanently available for ELECTRA in Cape Verde. Wind turbines should be procured through competitive bidding and basically evaluated on quality and guaranteed life-cycle price per unit of energy produced. It is stressed that the wind turbines must be of adequate quality with a proven record of operation and power performance. To minimize risks, it is recommended that wind turbines are approved in accordance with the Danish type approval requirements or similar for the local climate in Cape Verde (see Vol. 2, section 8.5).

Control system

The Step 2 shall as the Step 1 turbines be possible to operate also in case the wind farm monitoring and control system fails.

The Step 1 wind farm monitoring and control system is proposed to be modified/expanded with a facility that automatically limits the Step 2 wind farms output power in case the production exceeds a certain set maximum allowable level. The level should be decided on-line by the (diesel) power plant operators from the remote wind farm controller (PC) at the diesel power plant control room or optionally follow a preprogrammed curve related to the daily load pattern and the technical minimum load of the spinning diesel capacity. Remote manual start/stop of the individual wind turbines shall also be possible.

The proposed Step 2 Wind Farm project will give a wind energy penetration of approximately 25%. The staff responsible on all levels for Cape Verde's electricity supply will need to be fully informed and confident that the technology can be handled in the power system. The semi-automatic/manually based power system operation is chosen in order to facilitate the necessary know-how build up and transfer in ELECTRA. Training courses for planners, managers, engineers and operators particularly regarding combined power system operation and wind power's integration in conventional power systems will be crucial for optimal exploitation of wind energy in Cape Verde.

As to help the diesel power plant operators to operate the power system as efficient as possible still meeting the consumers demand at all times, two additional control system facilities are proposed:
- Indication of some (5 to 10) minutes forecast of wind power production. This will require installation of a wind measurement mast some 10 km upstream of the wind farms.
- Monitoring of each diesel generator production (10 min. avg. + std) and suggestion for start and stop.

It is stressed that the two above additions to the control system are crucial for the successful operation of the Step 2 wind farms, but considered to be valuable for the diesel power plant operators efforts to operate the power system efficiently.

Organizational and institutional aspects:

- Independent of the future structure of ELECTRA it is important to clarify the future ownership of the wind farms.
- Agreements concerning the land-ownership should be established as soon as possible and terms have to be clarified.
- The financing terms for ELECTRA and requirements to pay back loans (for the WTs) to the Government have to be clarified and settled.
- The present price structure for electricity and water in connection with the fuel prices (all fixed by the Government) determines the economic resources for ELECTRA and therefore also for the wind farms.
- The fuel savings in monetary terms due to wind energy production should be available and visible in ELECTRA's accounts

- The yearly budget for ELECTRA should explicitly contain allocation for the operation and maintenance of wind turbines as well as for training.
- The yearly report from ELECTRA should contain information on the production by wind energy and the fuel savings ascribed to the wind farms, also in monetary terms.
- Special attention should be given when the management of the wind farms is transferred from the engineering (planning) department of ELECTRA to the technical department

6. Draft Project Document

6.1 Context

6.1.1 The electricity supply subsector in Cape Verde

Government responsibilities for the energy sector are undertaken under the Ministry of Economic Coordination through its Directorate General for Industry and Energy (DGIE). DGIE is responsible for coordination and implementation of sector studies and national energy planning, policy and structure.

Generally, the energy sector organization and situation in Cape Verde varies considerably within the country. This is true particularly for the electricity supply subsector.

Electricity is basically provided from local isolated supply systems for the local communities. All community size electricity supply systems in Cape Verde are basically conventional diesel power stations, in certain cases supplemented with wind power generation from individual wind turbines or wind farms interconnected to the local diesel power station. The smaller supply systems are most often owned and operated by the local municipality, whereas the three larger supply systems are the responsibility of ELECTRA[1] , the national power company responsible for supply of electricity and water for Praia, Mindelo and Sal. ELECTRA does all planning, design, construction and operation of plants, including distribution to consumers. ELECTRA is a public utility company with its head quarters in Mindelo, with subsidiaries (Delegations) in Praia, S. Vicente and Sal, responsible for the operation locally, including wind farms. ELECTRA is also responsible for supply of fresh water, which involves desalination of sea water in order to cover the demand. Tariffs for electricity and water are regulated by the Government.

The Step 1 Wind Farm project consisting of 600, 900 and 900 kW wind farms in Sal, Praia and Mindelo, respectively, was implemented in 1994 by ELECTRA, with the director general of DGIE chairing the Project Steering Committee.

6.1.2 Plan and strategy for wind energy in the electricity subsector

The plans for the energy sector exist e.g. in the form of the "Development Strategies and Policies, 1992 -1995" presented at the Geneva Round Table Conference in 1992. The strategy and policy statements were made in a general form and are still operational and valid.

The policy for the electricity sector is to secure access to electricity at reasonable prices, thus facilitating development of the industrial sector and of the standard of living.

The energy policy of the Government underlines the importance of utilizing the natural energy resources available in Cape Verde as opposed to base electricity production entirely on imported fuels. The aim furthermore is to develop the local capacity to plan, construct and operate production facilities for utilization of natural renewable energy resources.

[1] Empresa Pública de Electricidade e Água

The highest priority among the renewable energy resources in the national development plan is given to wind energy. The extension of the grid to wind farms at the same time enables electrification of new areas for supplying small and larger scale industries and private consumers.

6.1.3 Donor cooperation in wind energy for electricity production

A number of wind energy projects for electricity generation have been and are in the process of being implemented in Cape Verde. Below is a brief list of some of the major projects, mentioning the project location, a brief description, Government implementing agency and donor:

project location	brief description	implementor	donor/investor
Ponta d'Agua - Praia	2x55kW Vestas - grid connected	INIT	UNSO/Danida
Assomada	1x55kW Bonus - wind/diesel	INIT	UNSO/Danida
Tarrafal	1x30kW Lagerwey - wind/diesel	MDR	Holland
Mt. R. Juliao - Mindelo	10x30kW Aeroman - grid connected	ELECTRA	Germany/KfW
Santa Maria - Sal	1x75kW Vestas - wind/diesel	Morabeza hotel	Morabeza hotel
Palmeira - Sal	2x300kW Nordtank - wind farm	ELECTRA	Danida
Mt. Montona - Mindelo	3x300kW Nordtank - wind farm	ELECTRA	Danida
Mt. S. Filipe - Praia	3x300kW Nordtank - wind farm	ELECTRA	Danida
Brava	1x150kW Nordtank - with dump load	municipality	Germany/KfW
Boa Vista	5x15kW Vergnet - wind farm and control	municipality	France

Status of the wind energy projects:

- Rehabilitation of Ponta d'Agua in the form of a 10-year major overhaul and relocation of the Assomada wind turbine have been agreed for financing by UNSO/Danida. The project awaits clarification of minor details regarding implementation methodology.
- Tarrafal has been transferred.
- Rehabilitation contract for Mte Juliao wind farm at Mindelo has been agreed for financing by Germany.
- Santa Maria, Palmeira, Mte Montona, Mt. St. Filipe and Brava operate.
- Boa Vista is under implementation.

The World Bank is p.t. in the process of undertaking a series of sector studies with the purpose of investigating possibilities for World Bank financing of projects in the sector.

A THERMIE Conference on Renewable Energies - Promotion of European Technologies - was held in Praia in November 1995. The EU is considering wind energy for possible future collaboration.

6.1.4 Economic context and institutional framework for wind farms

The only existing institution in Cape Verde capable of implementing and operating large wind farms is ELECTRA.

The investments in wind farms are treated no different from investments in conventional capacity. ELECTRA has financed the Step 1 Wind Farms on on-lending terms from the Government even though the project is a grant from Denmark. The terms are negotiable and will influence the financial situation of ELECTRA and in the end the electricity tariffs for consumers. The proposed wind farms are expected to enable a reduction of electricity tariffs or alternatively of ELECTRA deficits at the assumed financing conditions. Furthermore, the impact on external costs to the local and global society and environment will be positive, which may be considered when deciding financing terms from donors to the Government and terms for ELECTRA.

The structure of ELECTRA as well as terms and conditions for its operations may change in the years to come, particularly in a situation where no uniform structure in the energy sector has emerged. Several scenarios may be considered. It is however a technical necessity using today's technology that wind farms are interconnected to a conventional power station for which the wind farm will act as a saver of expenses. On top of financial savings for the power station, wind farms may generate savings for the society locally and globally. Institutionally, this project therefore assumes the wind farms to be an integrated part of ELECTRA, owned and operated by the same unit owning and operating the diesel power station and gaining the financial savings from the wind farm operations. Alternatively, very clear legislation and contractual conditions for generation and selling of wind power to the grid and/or conventional power plant operator must be developed.

6.2 Project justification

6.2.1 Problem to be addressed, the present situation

The overall core problem to be addressed by the project is to facilitate development of Cape Verde by satisfying the ever growing demand for electricity at the lowest possible cost and price for the consumers and yet acceptable for the environment, flora, fauna, and human health and safety in both the short and the long term.

The present situation is that

- the cost of electricity in Cape Verde is rather high due to the production in small isolated power systems primarily based on diesel generating sets running on heavy fuel and gasoil
- fuels are imported and local handling, storage, etc. is expensive
- a master plan for electricity supply in Praia, Mindelo and Sal foresees considerable growth in demand and loads, requiring large investments in new generation capacity
- wind farms in Praia, Mindelo and Sal of a total capacity of 2.4 MW have been in operation since December 1994, providing an average of 15% of the electricity consumption in 1995
- wind power is still a relatively "new" technology in rapid development, and wind power on a large scale with high wind energy penetration is new both in Cape Verde and in the world although more than 5000 MW is installed and in operation world-wide by the end of 1995
- the institutional capacity is limited and the number of staff members in the institutions involved with an in-depth knowledge of wind power compared to conventional diesel technology does not match the 15% the wind energy penetration level generated by the wind farms, so institutional development and increased awareness is needed
- the Feasibility Report studying Step 2 Wind Farms using the 1995 production data and statistics as input has shown prospects for future expansion of the wind farms at Praia, Mindelo and Sal, predicting considerably less costs of energy from wind farms than from diesel generation for the proposed expansion.

6.2.2 Expected End-of-Project situation

At the end of the project, the three wind farms at Praia, Mindelo and Sal have been expanded with installed wind turbine capacities of 1800 kW, 1200 kW and 600 kW, respectively. The wind farm expansions are connected through the existing wind farm grid connections with the necessary additional electrical cables and equipment. Wind farm monitoring and control systems and communication links have been expanded too and are now monitoring the expanded wind farm through one integral system. New remote facilities have been installed in the diesel power stations assisting the operators at the power station in their decisions - i.e. recommending starts and stops of diesels, showing forecasts of wind farm power production and enabling control of maximum allowable power output from wind farms. The wind power forecast is made based on a meteorological station located northeast of the wind farm and communicating with the wind farm monitoring and control system.

An additional wind energy production of 10200 MWh is supplied to the power systems from the wind farm expansions the first year after installation, increasing to more than 12000 MWh annually as the consumer loads develop.

Furthermore, an institutional support programme has been implemented, which has provided assistance during project implementation and thus through on-the-job collaboration led to design of appropriate operational strategy algorithms and development of the institutional capacity in ELECTRA with respect to planning, operation, power quality assessment and modeling of power systems with high wind energy penetration.

Finally, a study of the feasibility and recommendation on future wind farm expansion has been performed based on one years operational statistics of the expanded wind farms and a report has been presented.

6.2.3 Target beneficiaries

The beneficiaries of the project are the people of Cape Verde and the international community which benefit from reduced electricity prices in the short term and from reduced costs of generating electric energy in the long term, including externalities. The project furthermore provides a unique demonstration to the international community of a power supply system with high wind energy penetration.

6.2.4 Project strategy and implementation arrangements

The experiences from Step 1 of the Cape Verde Wind Farm project have been gathered and analyzed in the Feasibility Study. It is the recommendation of the Feasibility Study and of ELECTRA to use a project strategy and implementation arrangements which are practically identical to those used in the implementation of the Step 1 Wind Farm project, since the two projects are practically identical and since the Step 1 implementation is considered very successful. The organizational set-up should be similar with a turnkey wind turbine supplier, consultancies and ELECTRA as the implementing agency supervised by a project steering committee. The project implementation should follow the detailed recommendations of the feasibility study.

It is recommended that the necessary analyses of the dynamic and transient stability of the power system with expanded wind farms is done as an integral part of the project appraisal.

6.2.5 Institutional arrangements

ELECTRA is the responsible government implementing agency, with its Engineering Department as the responsible for all studies, planning and implementation of new projects. After Taking-Over from the contractors, the responsibility for operation and maintenance is transferred in ELECTRA to the Technical Department for exploration and production and subsequently to the local delegations. The Financial Department will be responsible for accounting both during project implementation and during operation.

The institutional arrangements and project organization chosen is the one that has emerged based on 3 years experience from the Step 1 Wind Farm project implementation as the most appropriate for such a project in Cape Verde with ELECTRA as project implementing agency.

6.2.6 Institutional support capacities

ELECTRA has shown in the Step 1 Wind Farm project a capacity to implement and operate a wind farm project, given the necessary institutional support during implementation. The present experience shows an ability in ELECTRA to operate wind farms up to high wind energy penetration levels - highest monthly average wind energy penetration in Sal is 36% and in Mindelo 21%. Given the necessary extended tools, training and institutional support in developing exact and structured procedures and methodologies, it is considered within ELECTRA's capacity to be able to operate an annual average wind energy penetration of up to 25%.

6.2.7 Reasons for donor assistance

Several donors have expressed an interest in considering funding of wind farm projects in Cape Verde due to the potential benefit for the development of the country and to the potential benefit for the local and global environment as compared to other alternative means of meeting the electricity demand.

6.3 Development objectives

The development objectives of the Government of Cape Verde as expressed by the Project Steering Committee are for Step 2 as for Step 1:

- to produce electricity as clean and cost efficiently as technically possible both in the short and in the long term
- to develop the use of Cape Verdean human and natural resources in the energy sector and to reduce imports, thus
  - improving the local capacity to plan, develop and operate the electric power supply system
  - reducing vulnerability to variations in fuel prices and possible global environmental fuel taxes as well as
  - improving the balance of trade

6.4 Immediate objectives

The immediate Step 2 project objectives for ELECTRA and for the Government of Cape Verde are:

- to extend the Step 1 Wind Farms to the feasible limit of wind energy penetration
  - which is financially attractive for ELECTRA and economically viable
  - which will not cause any unacceptable steady state voltage or frequency deviations, dynamic instabilities or violations of operational requirements for diesel gensets, and
  - which may be simply integrated in the present power system operation methodology

6.5 Outputs

The project outputs should best possibly meet objectives listed in Section 6.3 above.

The main output of the recommended project is three Step 2 Wind Farms of 600 kW, 1200 kW and 1800 kW in Sal, Mindelo and Praia, respectively, and the corresponding electricity production, meeting the immediate objectives best possibly at the present conditions and assumptions.

Sketch designs of Step 2 Wind Farms are in principle shown in Vol 2, Appendix F. The sketch designs, investment and energy production estimates and other assumptions have been made for wind turbines of a type similar to the existing Nordtank 300 kW. It should be noted, however, that the wind farms and the project could be implemented with any approved wind turbine type in accordance with the requirements specified in Section 8 of this report and by any experienced contractor living up to requirements similar to those applied in Step 1.

The project outputs can briefly be listed as follows

- A report with results of analyses of the dynamic and transient stability and recommendation of protective measures if needed for the three power systems - Praia, Mindelo and Sal - with the Step 2 Wind Farms and grid expansions as shown in sketch designs in Vol 2, Appendix F and described in Vol 2, section 10.

- Wind turbines for Step 2 Wind Farms at Praia, Mindelo and Sal with installed capacities of 600 kW, 1200 kW and 1800 kW in Sal, Mindelo and Praia, respectively, including design, manufacturing, transportation, installation, commissioning, instructions and manuals for operation and maintenance as well as an after sales service programme in an 18 months defects liability period.

- All necessary electrical LV grid connections, HV grid extensions, substations and grid reinforcements (see Vol 2, appendix F) as well as expanded wind farm monitoring and control systems and communication and new remote facilities in the diesel power station for recommendation of power system operation.

- One meteorological station for wind power forecasting at each of the Step 2 Wind Farms, located approximately 1-5 km northeast of the wind farm and communicating with the wind farm monitoring and control system and/or the remote facilities in the diesel power stations.

- An annual wind energy production and an impact on the electric power supply system as shown in Table 14 below :

Table 14 Estimated annual wind energy production and impact on the electric power supply systems of the recommended Step 2 Wind Farms at Sal, Mindelo and Praia.

		Sal	Mindelo	Praia
Existing Step 1 Wind Farm capacity (kW)		600	900	900
Recommended Step 2 Wind Farm expansion (kW)		600	1200	1800
Production data for first year after installation (1997)	Step 2 util. wind energy output (MWh/year)	1366	4723	4146
	Step 2 fuel savings (t/year)	288	1098	968
	Step 1+2 total util. wind energy output (MWh/year)	2835	9303	6585
	Step 1+2 fuel savings (t/year)	598	2151	1542
	wind energy penetration (%)	24	30	18
Levelised production data for the 20 years lifetime (1997-2016)	Step 2 util. wind energy output (MWh/year)	1446	5863	4777
	Step 2 fuel savings (t/year)	306	1331	1046
	Step 1+2 total util. wind energy output (MWh/year)	2915	10473	7217
	Step 1+2 fuel savings (t/year)	617	2378	1581
	wind energy penetration (%)	16	19	7.5

- Improved power system monitoring and control facilities at the control rooms of Praia, Mindelo and Sal power stations, enabling
  - 1-10 minutes wind energy production forecasting including an uncertainty estimation
  - a facility for limiting the maximum wind farm power output to a certain value set by the power station operator (in addition to the facility for remote start/stop of the individual wind turbine)
  - recommendations for power system operation, i.e. recommendations for power station operators of unit commitment - shut-down and start-up of diesel gensets

- Necessary access roads and civil constructions including wind turbine foundations and housing of equipment.

- Consumable spare parts for five years normal operation of the Step 2 Wind Farms.

- Supplementary equipment and tools necessary for erection, operation and maintenance of the Step 2 Wind Farms - excluding cranes and equipment for repair of fiber optic cables (it could be considered to include repair equipment for fiber optic cables depending on the development in this field in Cape Verde). The supplement depends on the type of wind turbine and the equipment and tools available for the Step 1 Wind Farms.

- Institutional support
  - Secretariat functions for the Project Steering Committee, including Project Progress Reports and Minutes of Project Steering Committee Meetings, both every 6 months.

- A specification of design requirements for remote facilities - including algorithm - in power stations, supplying power station operators with recommendations for power system operation - i.e. unit commitment decisions.
- A report assessing the power system performance and combined power system operation with Step 1 and Step 2 wind farms and recommendations on re-optimization of operational strategy for the power system after one year of operation of the Step 2 Wind Farms.
- A study of the feasibility and recommendation on future wind farm expansion.
- Assistance in dissemination of experience and results from operating power systems with high wind energy penetration
- 2 engineers in Engineering Department trained in modeling and analysis for power system expansion planning and power quality assessment with high wind energy penetration
- 2 engineers in Technical Department analysis and optimization of power system operation and power quality assessment with high wind energy penetration
- the technical staff of the local delegations' wind energy departments trained in operation and maintenance of the Step 2 Wind Farms

6.6 Project implementation methodology and strategy

In accordance with ELECTRA and the Project Steering Committee preferences, it is recommended that the project implementation methodology and thus organizational setup, type of consultancy services and contractors as well as the activities involved - including institutional support and training programmes - in principle should be similar to what has been applied in the implementation of the Step 1. It should , however, prior to any commitment be documented that the power system will be dynamically stable with the Step 2 Wind Farms. Such a study could be carried out in parallel with or as an integral part of a project appraisal. This implies:

- initial international consultancy services for dynamic power system analyses
- project appraisal
- international consultancy services for construction of wind farms
  - design of Step 2 Wind Farms and electric grid connections and extensions
  - tendering and contracting
  - coordination and supervision of works
- wind turbine turnkey contract for
  - supply of wind turbines, expansion of wind farm monitoring and control systems, meteorological stations for wind power forecasting and remote facilities in the diesel power stations for recommendation on power system operation
  - equipment for HV and LV electrical grid interconnection, monitoring and control systems and all communications
  - transportation and installation of wind turbines, monitoring and control systems, meteorological stations and remote facilities in diesel power stations
  - design and construction of wind turbine foundations
  - supply of necessary tools, consumable spare parts for 5 years normal operation as well as manuals for operation and maintenance
  - training in operation and maintenance
  - an after sales service programme for the 18 months defects liability period

- ELECTRA and subcontractors are responsible for
  - access roads and landscaping
  - local civil works and construction of shelters and housing for substations and equipment
  - electrical grid connection and grid extension works and installation
  - operation and maintenance in accordance with contractual agreements
- international consultancy services for institutional support, coordination and training
  - adviser and secretary to the Project Steering Committee
  - analyze, suggest and specify remote facilities and algorithm in power stations for on-line recommendation to power system operators regarding unit commitment decisions
  - monitoring and analysis of power system performance and operation
  - follow-up analyses and assessment after one year of operation of Step 2 Wind Farms for recommendation on re-optimization of power system operation with wind power
  - assistance in dissemination of results
  - feasibility study and recommendation on future wind power expansion
  - training in analyses and design optimization of power systems with high wind energy penetration

Any ELECTRA assistance to the wind turbine turnkey contractor should be in the form of subcontracts to his turnkey contract at clearly defined conditions, e.g.:

> crane assistance for the erection of wind turbines should be at clear contractual conditions sufficient to maintain acceptable insurances of all equipment throughout the construction period, but the crane assistance itself (including inter-island shipment of the crane) should be made available from ELECTRA as the owner of the crane free of charge for the wind turbine turnkey contractor.

6.7 Activities

The project implementation will involved the activities listed below:

- *Initiation and coordination*
  - Verification of dynamic stability of power system at the proposed Step 2 Wind Farm sizes - a precondition for the project
  - Contract consultants for actual project implementation
  - Prepare Detailed Work Programme
  - Design of wind farms and electric grid connection and extension
  - Prepare Technical specifications
  - Tendering and contracting of wind farm turnkey contract, equipment supplies & local works
  - Overall coordination and supervision of works
  - Progress reporting
  - Project Steering Committee meetings
  - Donor project monitoring and reviews
  - Project Completion Report

- *Step 2 Wind Farms*
  - Commencement WT works
  - Procurement and shipment of electrical equipment to be used for local electrical works and wind turbine foundations
  - Construction - local works civil and electrical works
  - Design and manufacturing of wind turbines
  - Construction of wind turbine foundations
  - Shipment of wind turbines
  - Erection and installation
  - Wind farm grid connection and running in, including remote facilities in the power station
  - Commissioning, Test on Completion and Taking Over
  - Training in operation and maintenance
  - Manufacturers after sales service programme
  - Monitoring defects liability

- *Institutional support*
  - Monitoring and analysis of power system performance and operation
  - Specification of design requirements and algorithm for remote facilities in power stations for power station operators, which shall supply recommendations for power system operation - i.e. in particular regarding unit commitment decisions
  - Follow-up analyses and assessment after six months of operation of Step 2 Wind Farms for recommendation on re-optimization of power system operation with wind power
  - Feasibility study and recommendation of future wind power expansion of the three power systems
    WT siting & wind farm layout
    Identify alternative development scenarios, including possibilities for demand side (consumer) management and optimization of power system operation (manual or automatic)
    System modeling
    Economic, financial and risk analyses
    Reporting
  - Assistance in dissemination of results - locally in ELECTRA and Cape Verde as well as internationally
  - Training in modeling, analyses and planning of power systems with high wind energy penetration

6.8 Inputs

See Budget which specifies inputs required, split up in recipient inputs and donor inputs.

6.9 Assumptions

Two preconditions for the project have been identified:
- that the dynamic and transient power system stability for operation with the Step 2 Wind Farms is analyzed and found acceptable
- that the local wind farm and diesel power station ownerships belong to the same financial unit - e.g. ELECTRA as today or ELECTRA delegations in a more or less privatized form

The further main assumptions are

Inputs:
- sufficient funding for implementation
- availability of land
- availability of adequate ELECTRA staff for implementation
- qualified proposals and turnkey contractor - i.e. similar or better quality and prices than Step 1 Wind Farms
- adequate wind turbine quality - Danish Type Approval (or similar) to local climate
- the large crane supplied in Step 1 is made available for Step 2 and wind turbines in Step 2 can be erected by this crane or by another crane permanently available in Cape Verde

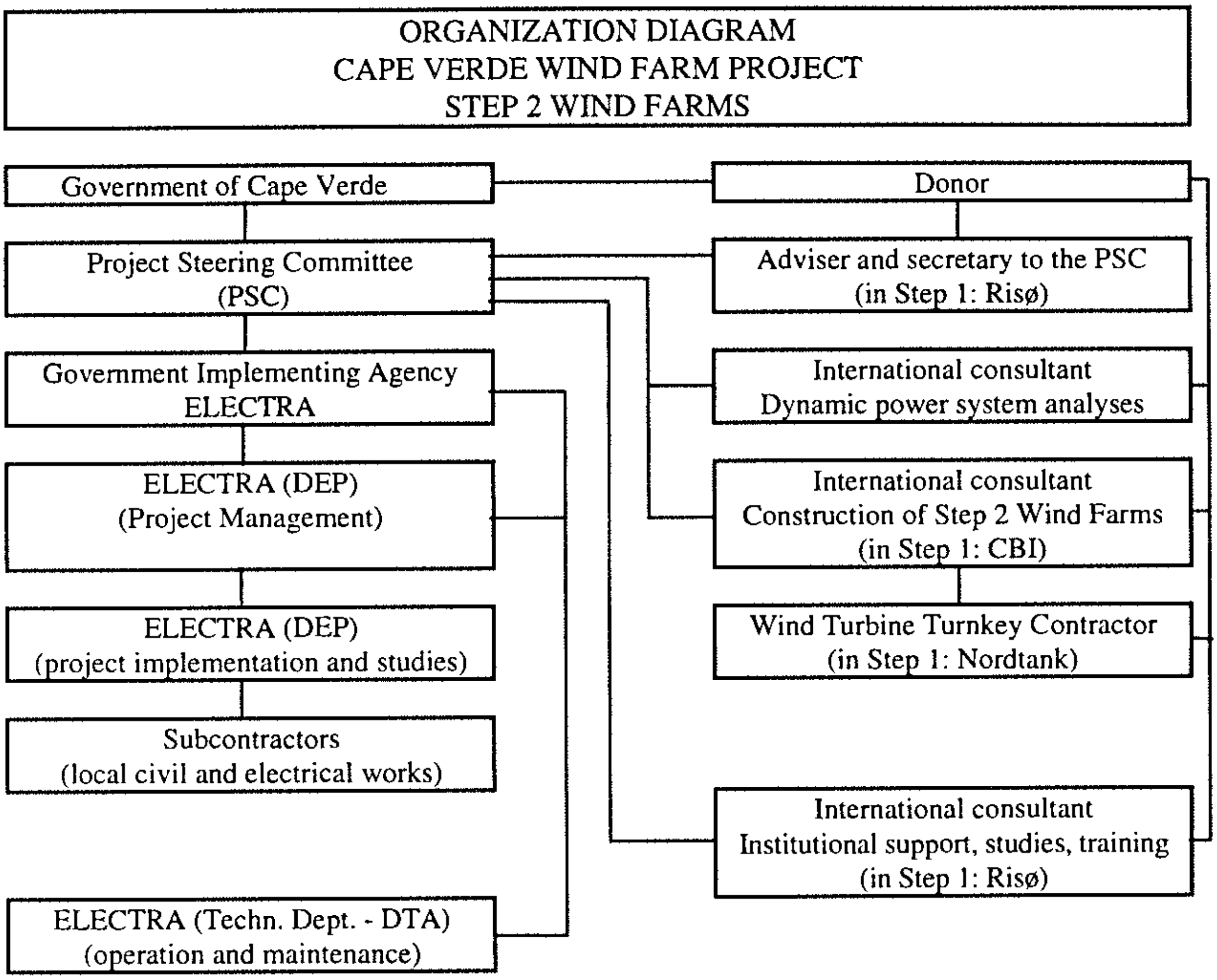
Activities, implementation and outputs:
- Step 2 Wind Farm project will be implemented by ELECTRA in a similar set-up and project organization to that used in Step 1
- experience from Step 1 Wind Farms is utilized in all aspects and phases of the project specification and implementation
- near future load, desalination and diesel capacity development according to firm plans - i.e. updated master plan as used in the feasibility study
- availability of grid and fiber optic cable
- completion of one year wind measurements at the Step 2 site at Mindelo (Selada Flamengo) and comparison to data from the Step 1 Wind Farm

Objectives:
- benefits from wind farm energy production - i.e. diesel power plant operation savings and capacity credit - are made visible in ELECTRA accounts, known to the public and used for actual electricity pricing and tariffs

6.10 Risks

The main project risks identified are:
- lack of financial sustainability of ELECTRA (the wind farm owner) to facilitate sustained operation and maintenance
- lack of adequate institutional awareness in ELECTRA and the Cape Verde government
- insufficient human resource development
- large drops in costs of fuel per ton for Cape Verde and ELECTRA, influencing the related savings from wind farm production
- inappropriate power system operation strategies for the combined operation with wind power
- lack of availability of crane for installation and O&M and of adequate transportation for the crane

6.11 Organization and administration



6.12 Organizational and financial sustainability

The project implementation and ownership of wind farms as well as diesel power stations are assumed to be in the same financial unit, e.g. ELECTRA as today. Savings from wind energy production will thus benefit the total power system efficiency and in itself provide the incentive for proper operation and maintenance of the wind farms.

6.13 Indicators and means of verification

Main indicators and the related means of verification for each wind farm and for the project in total are shown in the table below:

annual wind farm energy output	kWh meters and CMCS data and reports
wind farm technical availability	CMCS data and acceptable performance in Defects Liability Period
cost of wind energy output per kWh utilized	project evaluation
ELECTRA savings	ELECTRA accounts
adequate power system operation strategy	operators acceptance and report on power system performance
dissemination of results	presentation to various levels in society and government and at conferences as well as publications
future potential for wind power	feasibility report

6.14 Project review, reporting and evaluation

Depending on donor requirements.

6.15 Budget

The budget estimate for the project for implementing the proposed Step 2 Wind Farms is based on actual prices from Step 1. Details regarding wind farm investments are given in Vol 2, Section 13. All prices are at December 1995 price level.

Table 15 Budget estimate for proposed project - Step 2 Wind Farms

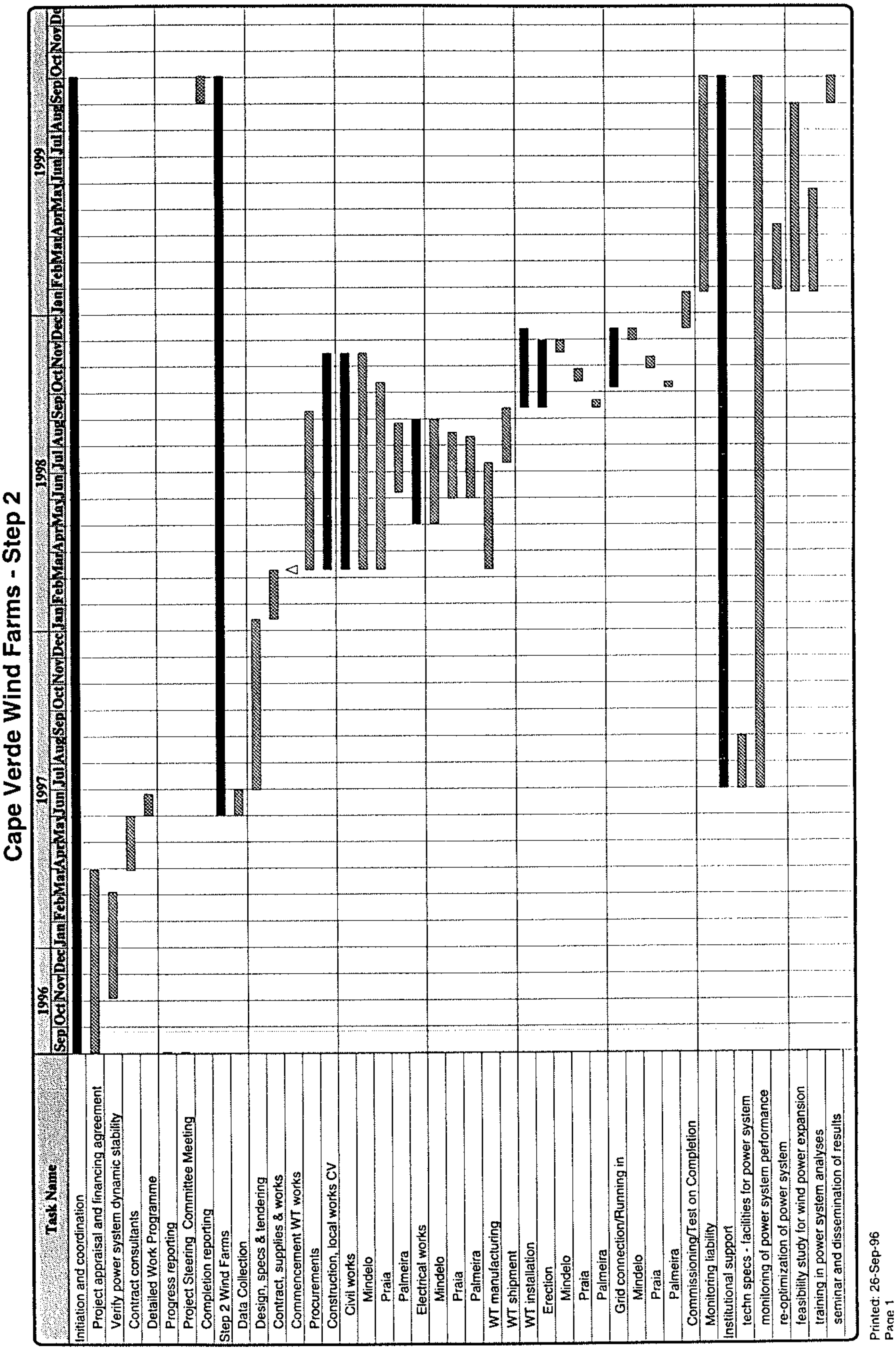
	PRAIA	MINDELO	SAL	TOTAL
Step 2 Wind Farms - installed capacity	*1800 kW*	*1200 kW*	*600 kW*	*3600 kW*
A. BUDGET FOR DONOR INPUT:				
Wind turbine turnkey contract	**kDKK**	**kDKK**	**kDKK**	**kDKK**
Wind turbines incl. installation, etc.	10500	7000	3500	21000
Grid connection	1500	1000	500	3000
Wind turbine foundations	450	300	150	900
Transport	1200	800	400	2400
Spares & tools	300	200	100	600
Equipment for fiber-optic communication	480	120	0	600
Equipment for grid extension	330	330	0	660
Modify CMCS incl. 300 kW dumpload	200	200	200	600
Met. station and remote facilities in power station	150	280	150	390
Design & manuals	200	200	200	600
After sales service	300	200	100	600
Training	250	250	250	750
Total - wind turbine turnkey contract	**15860**	**10880**	**5550**	**32290**
Technical assistance	**kDKK**	**kDKK**	**kDKK**	**kDKK**
contract 1 : Dynamic power system analyses				**350**
contract 2: Construction of Step 2 Wind Farms				**3000**
design of wind farms and grid				900
tendering and contracting				500
coordination and supervision of works				1600
contract 3: Institutional support				**3000**
secretary to the Project Steering Committee				750
specification of power system operation				500
monitoring of power system performance				300
re-optimization of power system operation				250
assistance in dissemination of results				200
feasibility study - future wind power expansion				750
training in power system analyses and optimization				250
Total - International consultants				**6350**
GRAND TOTAL - DONOR BUDGET (kDKK)				**38450**
B. BUDGET FOR CAPE VERDEAN INPUT:				
Local works, staff salaries, expenses	**kECV**	**kECV**	**kECV**	**kECV**
Wind farm building	0	800	0	800
Access roads	0	800	0	800
Cable trenching and laying	1475	1475	50	3000
Crane assistance incl. its transport	-	-	-	5000
Design, supervision, project management	-	-	-	2500
Land	-	-	-	0
Misc. expenses - local travels, shipments, etc.	-	-	-	5000
GRAND TOTAL - ELECTRA BUDGET (kECV)				**17100**

6.16 Accounting and auditing

In accordance with donor requirements. Expenses to be monitored by the Project Steering Committee.

6.17 Project Implementation Plan

A proposed project implementation plan based on the experience from Step 1 is shown on the next page:


Cape Verde Wind Farms - Step 2
Task Name
1996
1997
1998
1999
Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov De
Initiation and coordination
Project appraisal and financing agreement
Verify power system dynamic stability
Contract consultants
Detailed Work Programme
Progress reporting
Project Steering Committee Meeting
Completion reporting
Step 2 Wind Farms
Data Collection
Design, specs & tendering
Contract, supplies & works
Commencement WT works
Procurements
Construction, local works CV
Civil works
Mindelo
Praia
Palmeira
Electrical works
Mindelo
Praia
Palmeira
WT manufacturing
WT shipment
WT installation
Erection
Mindelo
Praia
Palmeira
Grid connection/Running in
Mindelo
Praia
Palmeira
Commissioning/Test on Completion
Monitoring liability
Institutional support
techn specs - facilities for power system
monitoring of power system performance
re-optimization of power system
feasibility study for wind power expansion
training in power system analyses
seminar and dissemination of results
Printed: 26-Sep-96
Page 1

Ministry of Foreign Affairs DANIDA

Cape Verde Wind Farms

Step 2

Feasibility Report

Vol. 2

TECHNICAL & ECONOMIC
POWER SYSTEM ANALYSIS

RISØ and ElsamProjekt

Ref No. 104.KapVerde.5.

September 1996

1. Background

The Wind Farm Project agreed between the Cape Verdean and Danish governments consists of

- Step 1 Wind Farms in the ELECTRA power systems at Praia, Mindelo and Sal with a total installed wind turbine capacity of 2.4 MW
- a feasibility study of the possibilities for expanding the Step 1 Wind Farms with a Step 2 at Praia, Mindelo and Sal.

The Cape Verde Wind Farm Project was effectively started in June 1992. The Step 1 Wind Farms have been completed and handed over to ELECTRA in December 1994. The present report concerns the feasibility study for Step 2 Wind Farms.

1.1 Cape Verde

The Republic of Cape Verde is situated in the Atlantic Ocean approximately 600 km west of Africa at latitudes 15-17°N and longitudes 23-25°W. The country has been an independent republic since 1975.

The lack of fresh water and electric energy are core problems for the development of Cape Verde. The country imports diesel fuel for electricity production for conventional consumption and for production of fresh water which is done by desalination of sea water.

Cape Verde

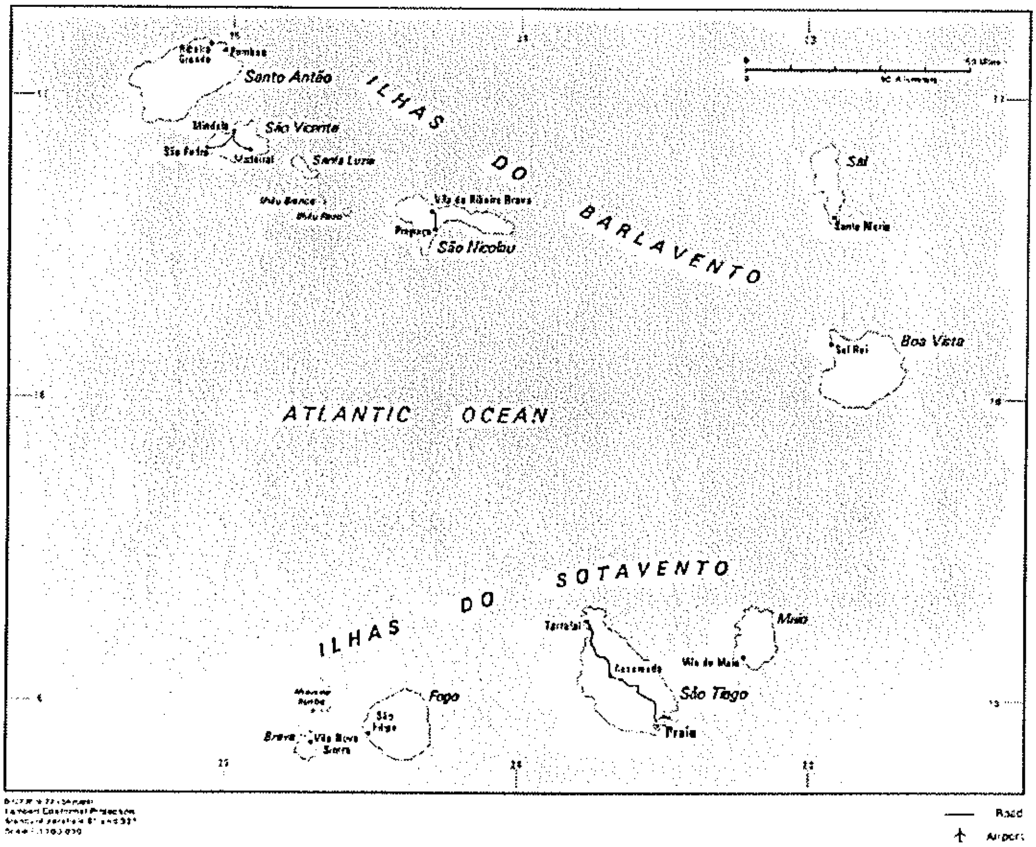


Figure 1.1 Cape Verde Islands

Praia is the capital of Cape Verde and houses about 24 % of the Cape Verde population, whereas about 15 % lives in Mindelo and about 2 % at Sal. The international airport is at Sal and the island houses a developing tourist resort.

Situated in the trade wind belt of steady north-easterly winds, Cape Verde has very favorable wind resources. The wind resources can be utilized for electricity production, saving imported fuel and reducing the cost of electricity and desalinated sea water.

The power supply in Cape Verde is based on diesel generator power plants organized in isolated power systems. ELECTRA, the national electric utility company, operates the power systems for Praia, Mindelo and Sal. The total installed diesel generator capacity ranges from about 3 MW at Sal to over 10 MW in both Praia and Mindelo.

ELECTRA is also responsible for desalination of sea water. Based on ELECTRA firm plans and on-going projects, the installed desalination capacity by 1996 is assumed to be 2400 m^3/day for Praia, 6500 m^3/day for Mindelo and 1250 m^3/day for Sal.

ELECTRA's cost of fuels are rather high compared to the world marked prices, partly due to the high costs of handling and storage in Cape Verde. In 1995 ELECTRA paid 19 ECV/l for gas oil,

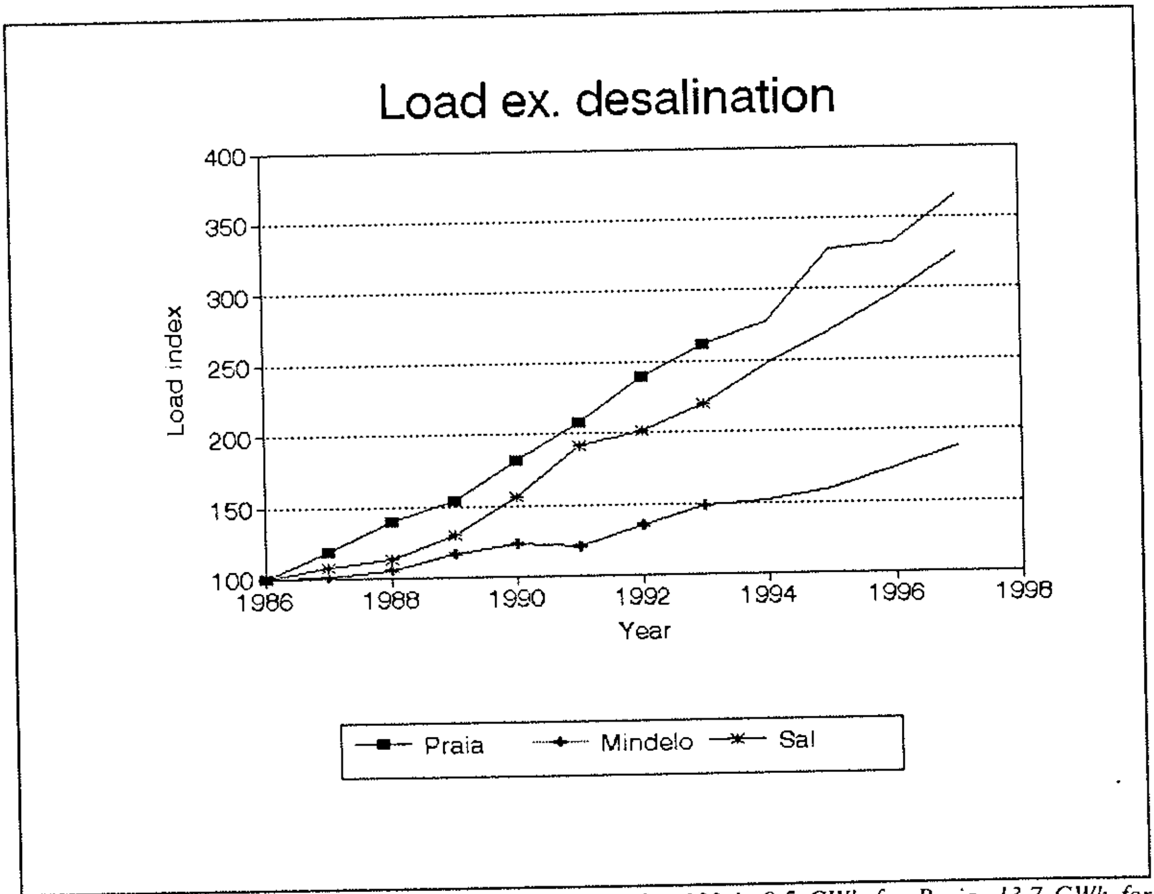


Figure 1.2 Historic load development and forecast. Index 100 is 9.5 GWh for Praia, 13.7 GWh for Mindelo and 2.3 GWh for Sal.

and for heavy fuel, 16500 ECV/ton in Praia and 14000 ECV/ton in Mindelo. At Sal, only gas oil is used. These costs of fuels makes wind power competitive which has been proven by the Step 1 Wind Farms.

The Step 1 Wind Farms included installation of three wind farms - 3x300 kW at Praia, 3x300 kW at Mindelo and 2x300 kW at Sal. The experience and data from the Step 1 Wind Farms forms a reliable background for studying the feasibility of further expansion with wind power.

Inhabited islands	9
Area	4000 km^2
Population (1990)	350 000
Capital	Praia
Avg. temperature	24° C
Annual rain fall	300-600 mm

Table 1.2 Cape Verde key data.

80 ECV/US$	6.5 DKK/US$	12.3 ECV/DKK

Table 1.1 Assumed currency conversions for 1996.

1.2 Scope of the feasibility study

The Feasibility Study (FS) shall explore the feasibility of expanding the wind component of the Cape Verde power systems further than the Step 1 Wind Farms.

The activities of the FS may be summarized as follows:

- Prepare detailed work plan for study.
- Technical power system data acquisition and measurements. Collect all necessary available information on existing power supply systems including grid, diesel generators, transformers etc., in Praia, Sal and Mindelo. Gather supplementary technical information from equipment suppliers on existing equipment and possible new equipment.
- Economic data acquisitions with respect to the power system including performing critical analyses of loads, needs and forecasts for step 2. Select and analyze the most suitable sites and layout for the additional wind turbine units.
- Identify and describe relevant technical alternative solutions for Step 2 system.
- Perform basic control system analysis.
- Steady state analysis of power system in order to identify special requirements to grid and control system design.
- Implement models of power systems and simulate power systems operation for evaluation of system logistics and economics.
- Perform economic and financial analysis of selected alternative system designs.
- Identify and perform analysis of risks connected to step 2.
- Prepare report(s) with Feasibility Study findings and recommendations for further work.

2. Status of power systems

Figures 2.1, 2.2 and 2.3 are sketches briefly describing the power systems configurations at Praia, Mindelo and Sal, status Sept. 1995. The sketches show the diesel genset units available at the diesel power stations, the grid connection of the Step 1 wind farms as well as an indication of the range and type of consumer loads. All grids are operated at 50 Hz.

Figure 2.1 Praia power system status Sept. 1995.

PRAIA POWER SYSTEM

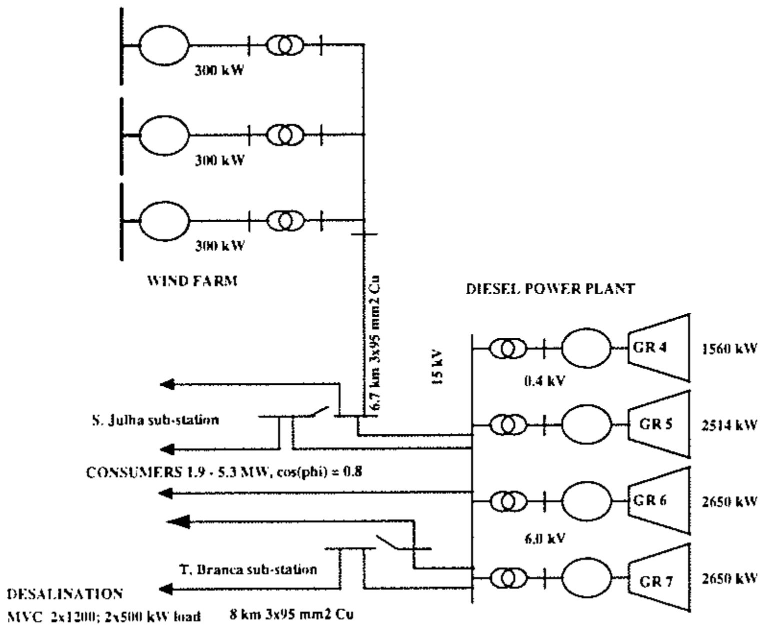


Figure 2.2 Mindelo power system status Sept. 1995.

MINDELO POWER SYSTEM

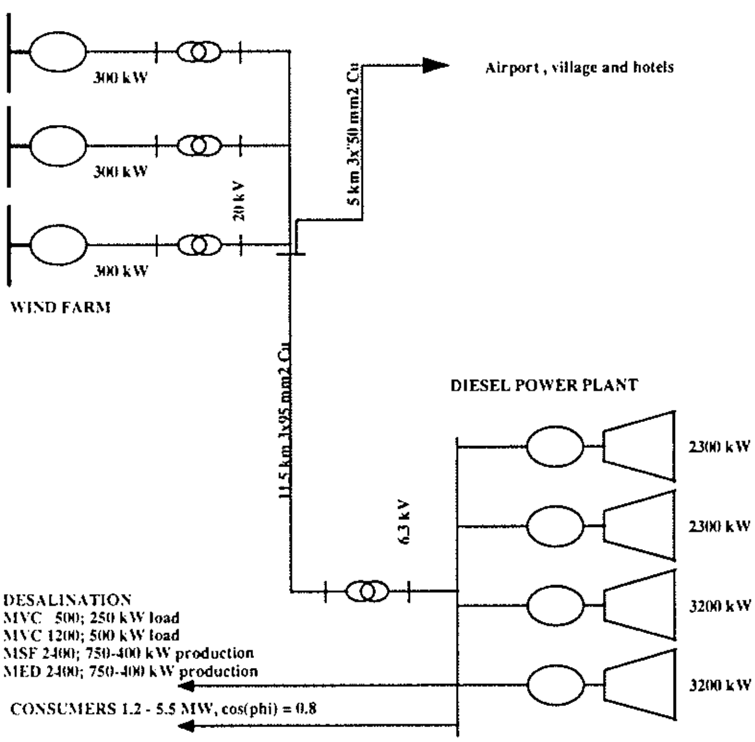
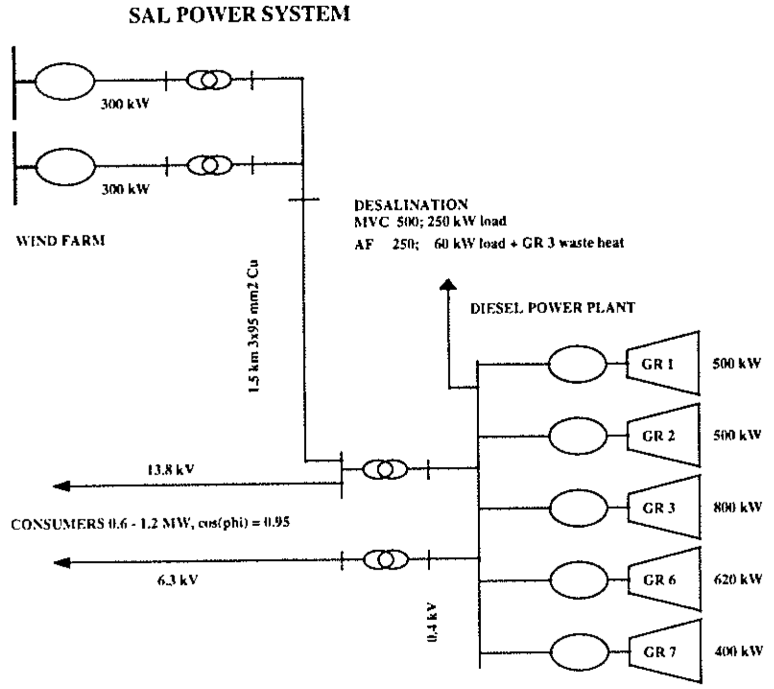


Figure 2.3 Sal power system status Sept. 1995.



2.1 Diesel power plants

The diesel power plants of Praia, Mindelo and Sal, status Sept. 1995 are specified in the tables below.

Table 2.1 Praia power plant status Sept. 1995.

Capacity (kW)	2650	2650	2514	1560	1000
Installed year	1992	1991	1967	1982	1986
Name	MAK VII	MAK VI	Deutz V	Deutz IV	Movel
Fuel	heavy	heavy	gas oil	gas oil	gas oil

Table 2.2 Mindelo power plant status Sept. 1995.

Capacity (kW)	3200	3200	2300	2300	600
Installed year	1994	1994	1984	1977	1989
Name	MAK VI	MAK V	Deutz IV	Deutz III	Movel
Fuel	heavy	heavy	heavy	gas oil	gas oil

Table 2.3 Sal power plant status Sept. 1995.

Capacity (kW)	800	500	500	620	400
Installed year	1990	1983	1983	1994	1994
Name	Cummins III	Cummins II	Cummins I	Movel	Deutz
Fuel	gas oil	gas oil	gas oil	gas oil	gas oil

Re. Praia power plant, firm plans exist to construct a new power plant consisting of two 3 MW heavy fuel units close to the newly installed desalination plant, i.e. about 9 km from the existing power plant. The new power plant is expected to be installed before 1998. As to cover the demand till then, two 2.5 MW units are expected to be installed at the existing power plant during 1996 and 1997.

The new Mindelo power plant were commissioned in 1994, and is now in normal operation. There exists no firm plans for further near future expansion of the diesel capacity in Mindelo.

Firm plans at Sal exist for a new power plant with 2x1000 kW gas oil units to be installed close to the existing power plant. The new power plant is planned to be commissioned before within 1997.

2.2 Wind turbines

The installed wind turbine capacity is specified in table 2.4 below. In relation to the "old" wind turbine capacity, i.e. capacity installed prior to the Step 1 wind farms, it should be noted that this capacity only in Sal in currently in operation. Re. the 2x55 kW wind turbines in Praia, funding from UNSO is available and decision is taken to service the wind turbines and bring them back to operation asap. Plans for rehabilitation of the 10x30 kW wind turbines is Mindelo are uncertain.

Table 2.4 Cape Verde grid connected wind turbines, status Sept. 1995.

	Praia	Mindelo	Sal
"Old" wind power capacity (kW)	2x55	10x30	1x55
Estimated annual output (MWh/y)	220	740	70
Step I wind power capacity (kW)	3x300	3x300	2x300
Estimated annual output (MWh/y)	3560	3770	1850
Total wind energy output (MWh/y)	3780	4510	1920

2.3 Desalination plants

Table 2.5 specifies the desalination plants as installed in Praia, Mindelo and Sal (status Sept. 1995). The desalination plants are:

MVC Mechanical Vapor Compressor, electric load
MSF Multi Stage Flush, includes boiler and gas turbine
MED Multi Effect Destiller
AF Auto Flush, electric load + waste heat from power plant

In Praia and Mindelo, as can be seen from table 2.5, new desalination capacity is under construction. At Sal, new desalination capacity in terms of one MVC 500 unit is planned to be installed asap and within 1996.

Table 2.5 Sea-water desalination as installed at Praia, Mindelo and Sal, status Sept. 1995.

Location	Type	Capacity (m^3/24h)	Consumption	Comment
Praia	MVC	2x1200	2x500 kW el.	Water intake under construction in Sept. 95, plant is assumed to be commissioned before 1996.
Mindelo	MVC	500	250 kW el.	
	MSF	2400	875 kg/h fuel	Generator can't sync. to grid
	MVC	1200	500 kW el.	
	MED	2400		Under construction, expected to be commissioned in 1996. Generator may supply 400 - 750 kW el. to the grid.
Sal	AF	360	power plant waste heat & about 8 kWh/m^3 el.	
	MVC	500	250 kW el.	

3. Experience from Step 1 Wind Farms project implementation

The wind farms were installed during Oct-Nov 1994 and commissioned 09 Dec 1994. Data from the Oct-Dec 1994 therefore is not considered representative for long-term operation and expectations. The focus of this analysis will be on the first six months of 1995, i.e. Jan-Jun 1995. This period would be expected to be a sort of running-in period for the power system operation during which the feasibility of the different wind energy penetration levels could be proven.

Some key data from the operation of the power systems with wind power for the period Jan-Jun 1995 are presented in Table 3.1.

A brief analysis and some comments are given below for key features of the data.

Table 3.1 Operational statistics - Actual data for Sal, Mindelo and Praia power systems, Jan - Jun 1995

	Sal	Mindelo	Praia
Installed wind turb. capacity (kW)	600	900	900
Avg. wind speed at hubheight (m/s)	7.8	11.6	8.6
Wind energy production (MWh)	893	2655	1596
Wind turbine availability (%)	99	97	99
Total WT availability incl grid (%)	93.5	92.4	98.8
Avg. wind turb. capacity factor (%)	35	68	41

3.1 Implementation

The three Step 1 Wind Farms were completed in December 1995 by Nordtank as wind turbine turn-key contractor with Carl Bro International (CBI) as the consulting engineer responsible for technical specifications, tendering and supervision of works. CBI used Elsamprojekt as subconsultant for design of electrical grid extensions. Local electrical works were executed by ELECTRA, civil works by subcontractors to ELECTRA, and road works and cable trenching by ELECTRA with assistance from the municipality in Mindelo and the Ministry of Infrastructure in Praia. Risø has assisted the project steering committee and coordination as well as provided technical assistance for ELECTRA and CBI regarding wind farm siting, layout, design, tender evaluation, performance monitoring and power system operation.

The project was by-and-large implemented within the budget and period of time available according to the contracts. Certain parts of the local works were delayed but other parts were completed faster than assumed. Planning of Step 2 should take into consideration that possible shortages of equipment in Cape Verde may cause delays of the local works.

Further information is available from contracts, minutes of site meetings, progress reports, minutes of project steering committee meetings and from correspondence.

During the FS, the team has held meetings with ELECTRA direction and delegations, the project steering committee and the municipalities requesting preferences and ideas or suggestions for design and implementation methodology of Step 2. Basically, all parties have expressed satisfaction with the Step 1 project implementation and design.

Step 2 should to the degree possible follow the Step 1 methodology of implementation. The Step 2 should be designed as an extension of Step 1 to the limit of wind energy penetration which is economically viable and can be proven to not cause any unacceptable steady state voltage or frequency deviations, dynamic instabilities, violation of operational requirements for diesel gensets or insurmountable operational complications. Actually, the power systems shall continue to be manually operated from the diesel power stations' control rooms. However, it has been agreed that Step 2 should include a facility providing monitoring of system operation and guidance for diesel genset start and stop actions.

3.2 Wind turbine operation and availability

Wind turbine and grid availability is in Table 3.1 given as
a) average wind turbine availability including only non-availability due to technical problems or maintenance of the wind turbine itself, and
b) the resulting average technical availability of the individual wind turbines including electric grid problems and remote stops by power system operators.

The availability is determined based on the log-books recorded for the months Mar, Apr, May and Jun 95. Unfortunately, log-books recorded by the control systems for Jan and Feb 95 have been lost.

85% of the outage time (lost availability) at Sal and 60% of the outage time at Mindelo were due to remote stops activated by the diesel power station operators in periods with either low loads or other regulation problems which were attributed to the wind farms. At Praia almost no remote stops have occured due to the low wind energy penetration.

An analysis at Mindelo lead to a modification of the operational strategy of the diesel power station as well as a repair of the voltage controller of the diesel gensets, which has practically removed the need for remote stops. The grid availability is therefore expected to increase at Mindelo. At Sal, however, remote stops cannot be avoided at the present consumer load levels.

The only significant wind turbine availability problem observed is "over-heating" of generators at Mindelo, which has caused an approximately 2% loss of availability as an average for the three wind turbines. The "over-heating" is mainly a control system problem which is in the process of being corrected.

3.3 Wind energy production/wind turbine performance

The actual (annual) wind turbine capacity factors might be considered some 10% lower than reported in Table 3.1. The maximum power output of the wind turbines according to the guaranteed power curve is higher than the wind turbine rating of 300 kW. The power output reaches of the order of 330 kW at rated wind speed, varying from site to site depending on the air density. However, it is still extremely high average capacity factor values for 6 months of operation - in Mindelo surely among the highest in the world for a standard wind turbine. As seen from the availability analysis above, the capacity factor could even have been 5-10% higher if unnecessary remote stops and "over-heating" of generators had been avoided.

3.4 Economics

Overview of actual Step 1 expenses according to contracts:

Cape Verde Step 1 Wind Frams	Mindelo	Praia	Sal	Total
No of WT's	3	3	2	8
Wind capacity (kW)	900	900	600	2400
Grid extention 3x95 Cu	11.5	7	1.5	20
Fiber optic	11.5	9	1.5	22

Final contract sum	Mindelo DKK	Praia DKK	Sal DKK	Total DKK	Total DKK/kW	Distribution %
Consultancy	1365000	1365000	910000	3640000	1517	8.48
Local works	1199880	1199880	799920	3199680	1333	7.46
Preliminaries	403545	403545	269030	1076120	448	2.51
Erection Crane	1783425	1783425	1188950	4755800	1982	11.08
Training in DK	253279	253279	168853	675410	281	1.57
Training in CV	24263	24263	16175	64700	27	0.15
After sales service	168750	168750	112500	450000	188	1.05
Manuals & Drawings	26250	26250	17500	70000	29	0.16
Provisional sum	280294	280294	186863	747450	311	1.74
Wind Farm	6619374	6626985	4602010	17848369	7437	41.59
Met. Station	133700	133700	133700	401100	167	0.93
On Site Training	43500	43500	43500	130500	54	0.30
Car	125300	125300	125300	375900	157	0.88
Electrical Eq. Supp	2760405	2013014	1031541	5804960	2419	13.53
Tools & Spares	313264	313272	278152	904688	377	2.11
Design & Manuals	245000	245000	245000	735000	306	1.71
Remote Control	801069	717298	240529	1758896	733	4.10
Electrical Service	68100	68100	68100	204300	85	0.48
Furniture	14809	14809	14809	44427	19	0.10
WT workshop	28000	0	0	28000	12	0.07
Grand total				**42915300**	**17881**	**100.00**
Sum final Nordtank contract				**36075620**	**15032**	**84**

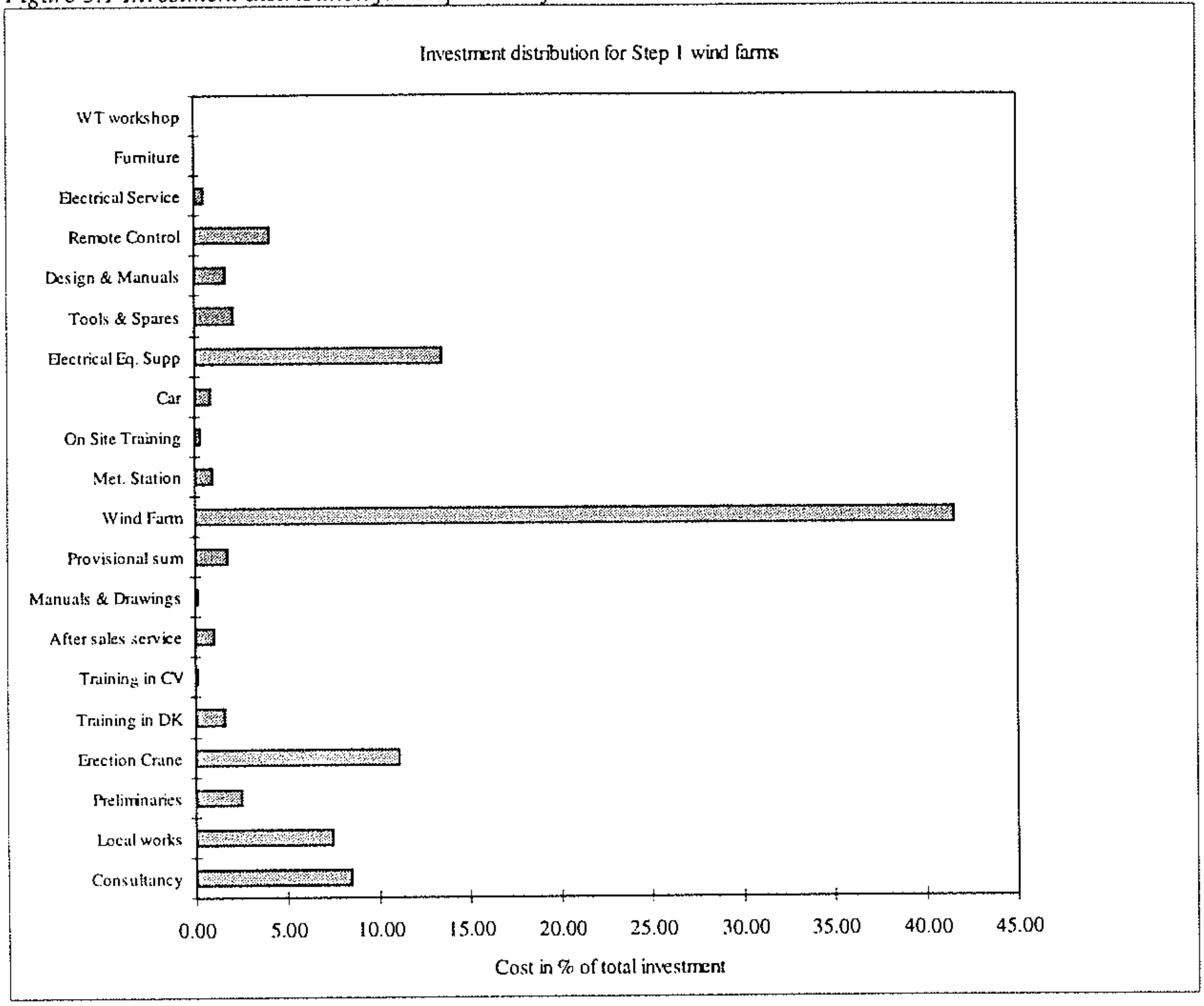
Local works (Electra)					
Site prep. costs	480000	32000	32000	544000	227
Wind farm building	224000	224000	224000	672000	280
Roads	320000	480000	32000	832000	347
Cable trench	480000	480000	160000	1120000	467
Others (mangement etc.)	10560	10560	10560	31680	13
Sum local works				**3199680**	**1333**

Consultancy		
CBI	3000000	1250
Risø	640000	267
Sum consultancy	**3640000**	**1517**

FS for Step 2		
Electra		0
Risø	3044000	1268
Sum FS	**3044000**	**1268**

Coordination		
Electra		0
Risø	1219000	508
Sum Coordination	**1219000**	**508**

Figure 3.1 Investment distribution for Step 1 wind farms.



4. Power system performance with Step 1 wind farms

4.1 Power quality assessment

During the FS three measurement campaigns for each of the power systems have been performed together with ELCTRA, i.e. one campaign prior to the installation of the wind farms, one campaign during commissioning and one after. The campaigns are described in detail in Summary of Discussions Dec. 93, Nov. 94 and May 95. Analyses of the measurements have been prepared giving the following indications:

- The Step 1 wind turbines do not have a severe impact on the steady state voltage and frequency. The measured steady state voltage and frequency are well within the normally adopted international standards, e.g. CENELEC EN50160 *Voltage characteristics of electricity supplied by public distribution systems* European Committee for Electrotechnical Standardization (1995).
- Severe voltage unbalances have been observed in both Praia, Mindelo and Sal. The voltage unbalance is not caused by the Step 1 wind turbines, but may if not kept below an acceptable low level force the wind turbines out of operation. In May 95, the voltage unbalances were within acceptable limits for Mindelo and Sal, whereas for Praia the voltage unbalance was exceeding 2 %, i.e. the maximum allowable level according to CENELEC EN50160. Electra will take action as to reduce the voltage unbalance in Praia.
- The Step 1 wind turbines reduce the power factor at the diesel power plant as the wind turbines produce active power and consume reactive power. This leaves the diesel power plant at a lower active load and a higher reactive load than it would have been without the wind power in the system. As long as sufficient spinning capacity is maintained for supplying the needed active and reactive power, the reduced power factor operation will not introduce any critical conditions.
- The Step 1 wind turbines produce a variable output power which superimposes load fluctuations on the diesel power plant. The fluctuations cause increased governor operation as to maintain a close to constant grid frequency. Severe fluctuations are not observed.

The measurements are further described in the two next sub-sections. Section 4.1.1 considers the grid measurements, whereas section 4.1.2 reports the power plant measurements.

4.1.1 Grid measurements

Grid measurements have been performed using two of ELECTRA's VIP System 3 Power Analyzers with 128 kB memory packs. The VIP System 3 Power Analyzer stores for each sample to the memory pack instantaneous values of voltage and frequency, instantaneous and average values of active and reactive power as well as a number other values. A complete list of the stored values is enclosed in Appendix A.

The sampling rate for the measurement campaigns was set to 5 minutes allowing for continuos measurements during approximately 2 days before the memory pack had to be emptied.

Instantaneous values of total active and reactive power, the three line voltages and the grid frequency have been extracted from the raw data files (*.CMP) and analyzed. The data files are specified in table 4.1. Time series plots of the analyzed data are enclosed in Appendix A.

Table 4.1 Specification of data files recorded by the VIP power analyzers.

PRAIA	Nov/Dec 93	Oct/Nov 94	May 95
Power plant 15 kV feeder Fazenda I	1fazen1.cmp - 1fazen3.cmp	1fazen4.cmp - 1fazen5.cmp	1fazen6.cmp - 1fazen9.cmp
Power plant 15 kV feeder Fazenda II	2fazen1.cmp - 2fazen3.cmp		
Wind turbine #1 0.4 kV feeder		pra1wt1.cmp	
Wind farm 15 kV feeder		prawf1.cmp - prawf3.cmp	prawf4.cmp - prawf6.cmp
MINDELO	Nov/Dec 93	Oct/Nov 94	May 95
Power plant 6.3 kV feeder Zona Sul	sul1.cmp - sul3.cmp		
Power plant 6.3 kV feeder Joao Belo	jbelo1.cmp - jbelo3.cmp		
Power plant wind farm 6.3 kV feeder		minpw1.cmp - minpw2.cmp	minpw3.cmp - minpw6.cmp
Wind farm 20 kV feeder			minwp1.cmp - minwp3.cmp
SAL	Nov/Dec 93	Oct/Nov 94	May 95
Wind farm 13.8 kV feeder		salwp1.cmp - salwp3.cmp	salwp4.cmp - salwp6.cmp
Power plant 13.8 kV feeder	salpp1.cmp - salpp3.cmp	salpp4.cmp - salpp7.cmp salpp8.cmp - salpp9.cmp	salpp10.cmp - salpp11.cmp
Hotel Belo Horizonte transformer 13,8 kV feeder	beloh1.cmp - beloh3.cmp	beloh4.cmp - beloh6.cmp	beloh7.cmp - beloh8.cmp

4.1.1.1 Steady state voltage and frequency

The measured time series as recorded by the VIP power analyzers has been further analyzed as to obtain the plots in figure 4.1 to 4.8.

Figure 4.1 and 4.2 compares variations in voltage and frequency prior, during and after the installation of the wind farms.

Figure 4.1 shows that the measured voltage variations in 95 % of the time (assuming the variations to be Gausian distributed) is less than 2 % of the nominal voltage. It is seen that the voltage variations are not dramatically changed from 1993 to 1995 for either Praia or Sal. The voltage variations measured at Mindelo power plant, however, are reduced from 1993 to 1995. This is most probable due to the installation of the new power plant in Mindelo in 1994, which after some problems during running in, seemingly has improved the voltage quality in Mindelo.

Figure 4.2 shows that the measured frequency variations in 95 % of the time (assuming the variations to be Gausian distributed) is less than 0.5 Hz. It is seen that the frequency variations are not dramatically changed from 1993 to 1995.

Figure 4.3 to 4.8 show measured instantaneous voltage and frequency as a function of the wind farms output power.

The graphs in figure 4.3, 4.5 and 4.7 show how the grid voltage at the wind farms varies depending on the wind farms output power.

- In Praia, figure 4.3, the trend is that an increased wind power production gives a small increase in the voltage at the wind farm. The difference from the nominal 15 kV is between -1.7 % and 2.3 %.
- In Mindelo, figure 4.5, the trend is the same as for Praia for outputs below 500 kW, whereas for higher outputs the voltage is decreasing. The voltage decrement at outputs above 500 kW can be explained by reactive losses in the connection between the power plant and the wind farm and possibly manual reduction in the voltage setpoint at the power plant during periods with high wind power production. The difference from the nominal 20 kV is between -0.3 % and -3.8 %. It is noted that the voltage is below the nominal 20 kV also at no load, indicating that the voltage setpoint at the power plant is too low and/or that the 6.3/20 kV transformer connecting the wind farm feeder to the power plant should have a higher secondary voltage.
- At Sal, figure 4.7, an increased wind power production gives a small voltage decrement at the wind farm. The voltage decrement is explained as for Mindelo, with the modification that manual reduction in the voltage setpoint at the power plant during periods with high wind power production is probably the main explanation for the case at Sal.

Re. manual voltage reduction at the power plant during periods with high wind power production, this may be because the power plant operators tend to adjust the voltage setpoint downwards as to maintain a high power factor at the diesel power plant. This has been discussed with Electra both at Sal and in Mindelo, and Electra is aware that this may not be a good practice as lowering the voltage increases losses and may actually cause too low voltage at consumers on heavy loaded feeders.

The graphs in figure 4.4, 4.6 and 4.8 indicate that the grid frequency basically remains unchanged and does not depend on the wind farms output power.

Figure 4.1 Comparison of voltage variations prior, during and after commissioning of the Step 1 wind farms.

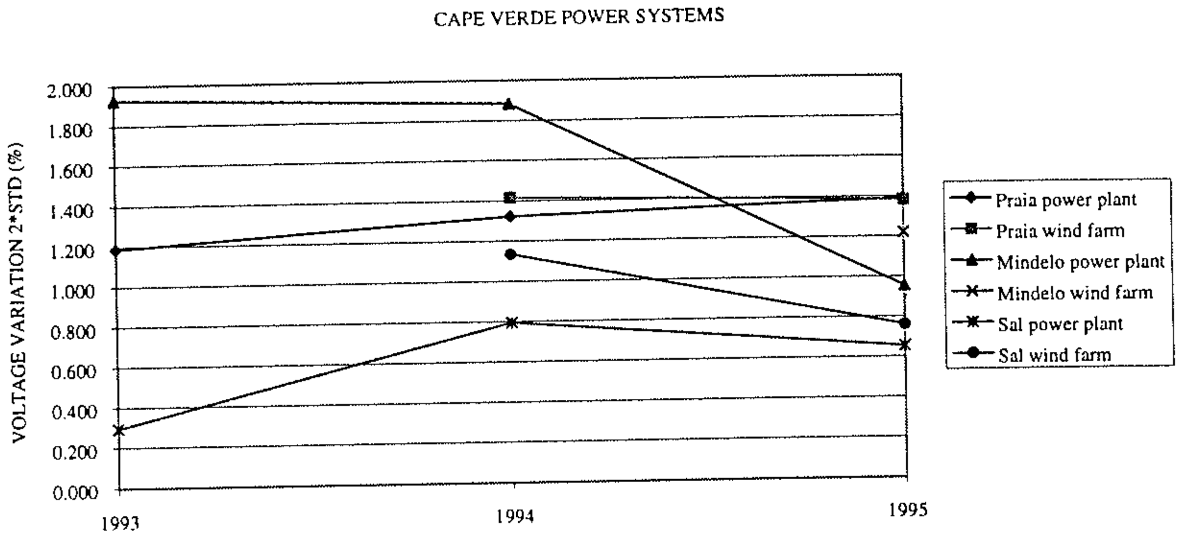


Figure 4.2 Comparison of measured frequency variations prior, during and after commissioning of the Step 1 wind farms.

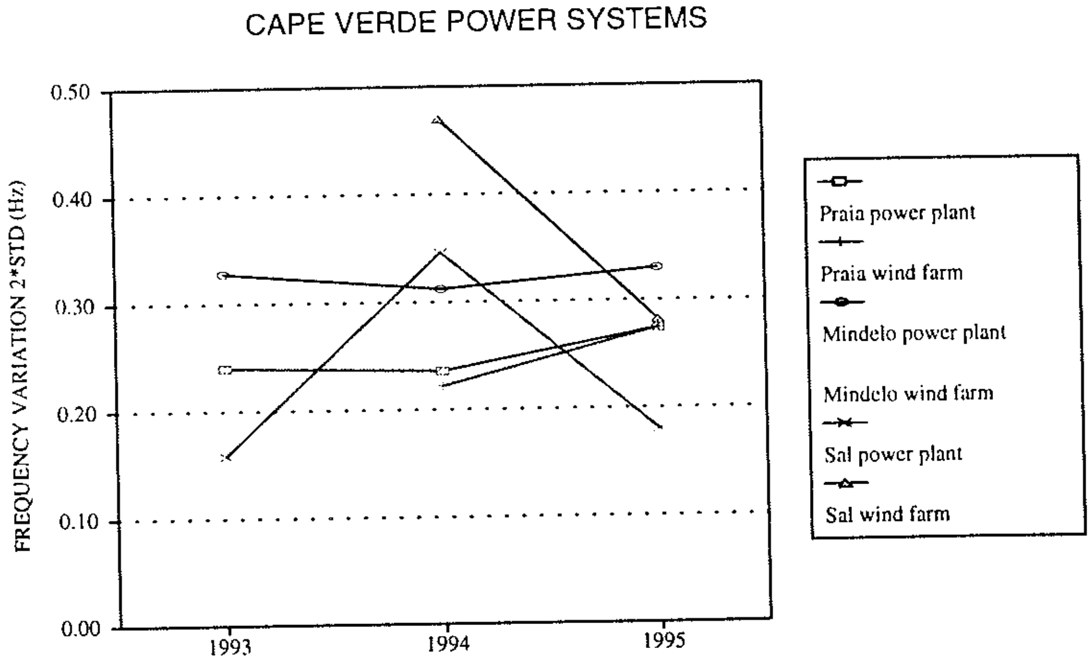


Figure 4.3 Measured instantaneous grid voltage at Praia wind farm as a function of the wind power output, May 95.

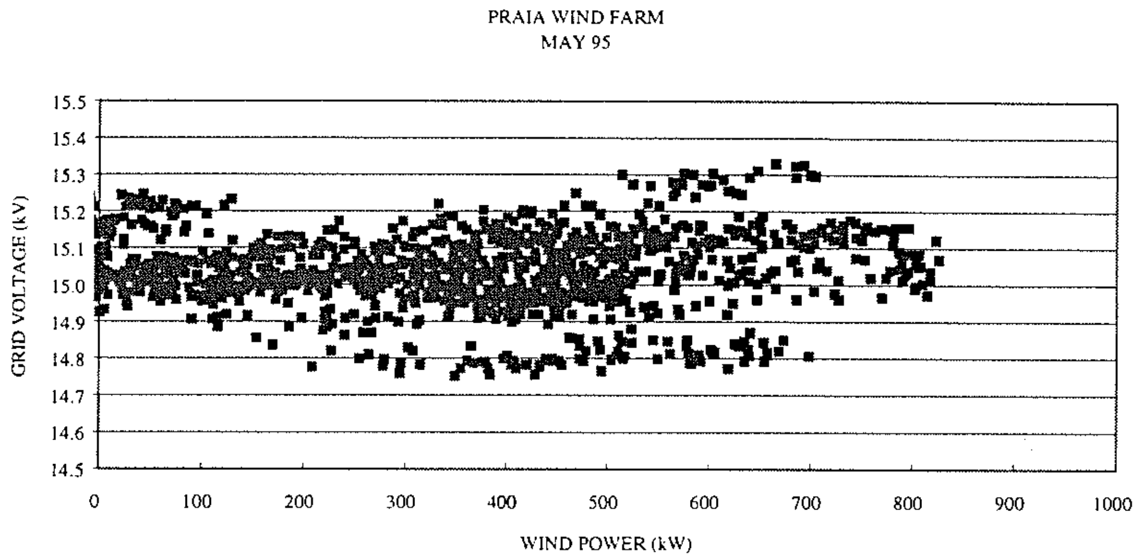


Figure 4.4 Measured instantaneous grid frequency at Praia wind farm as a function of the wind power output, May 95.

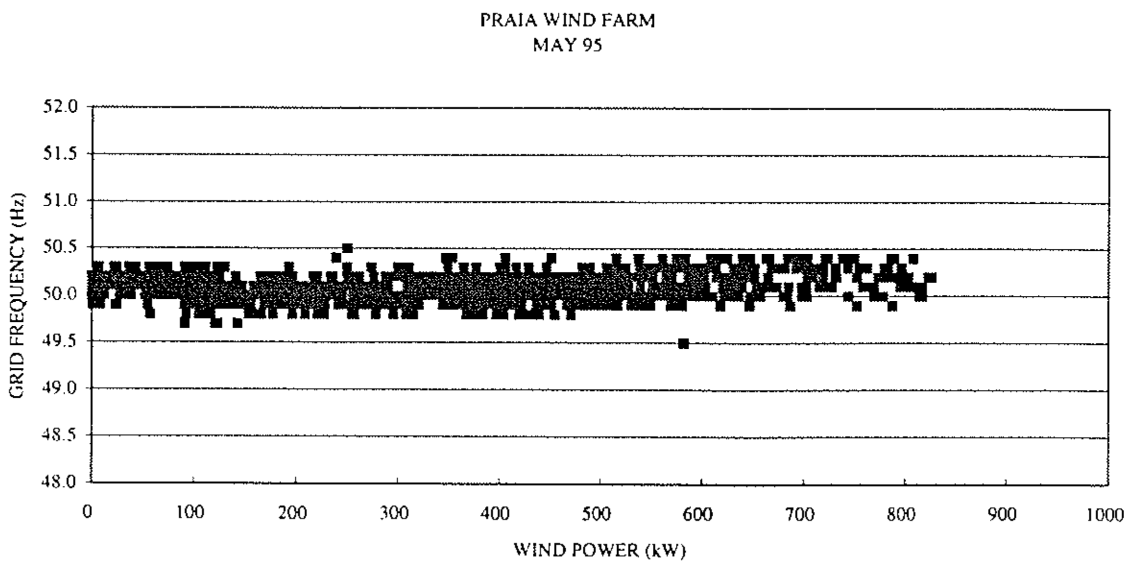


Figure 4.5 Measured instantaneous grid voltage at Mindelo wind farm as a function of the wind power output, May 95.

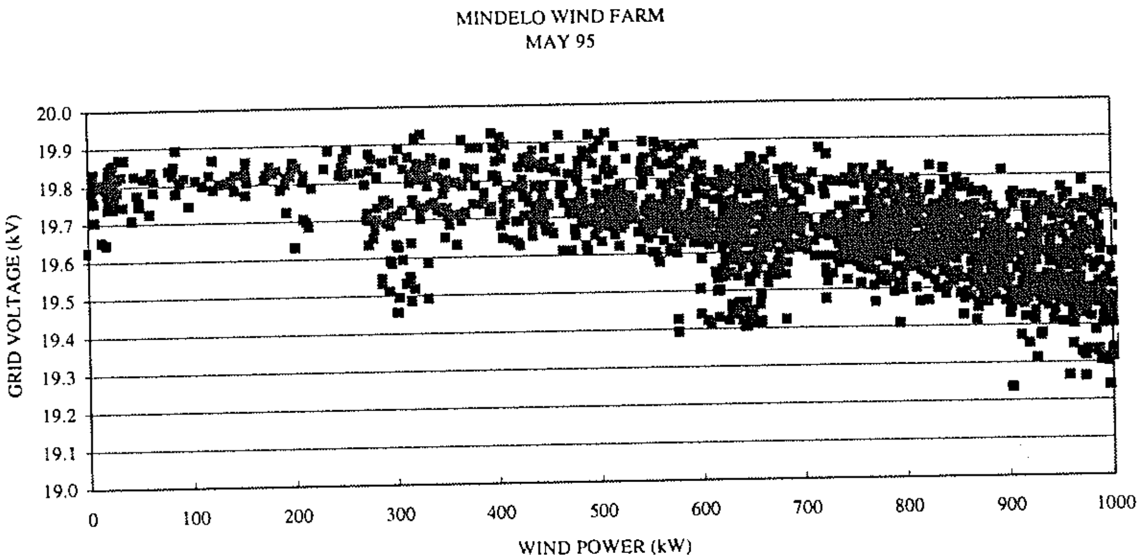


Figure 4.6 Measured instantaneous grid frequency at Mindelo wind farm as a function of the wind power output, May 95.

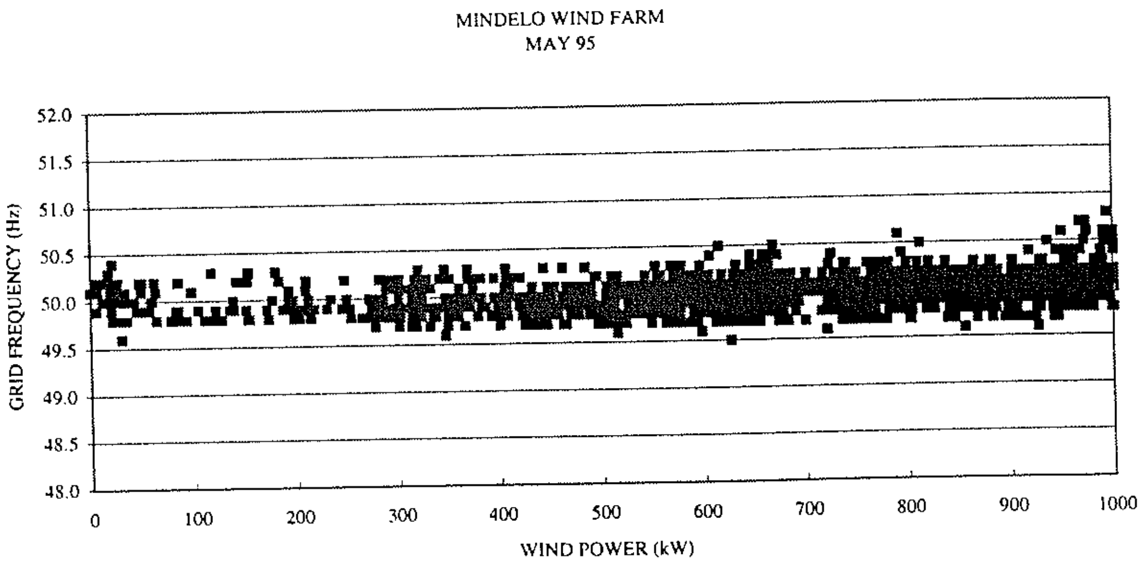


Figure 4.7 Measured instantaneous grid voltage at Sal wind farm as a function of the wind power output, May 95.

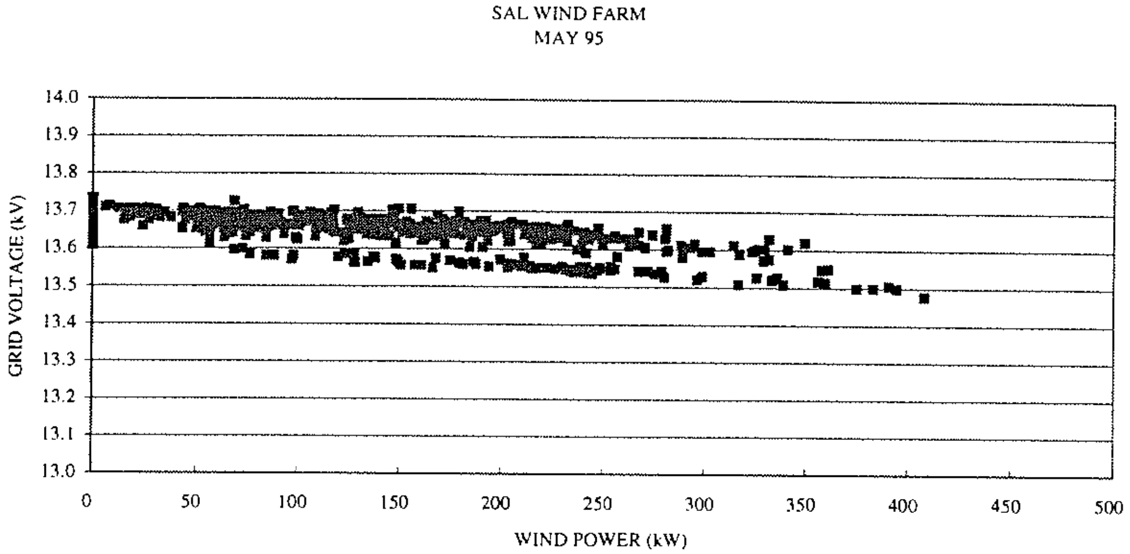
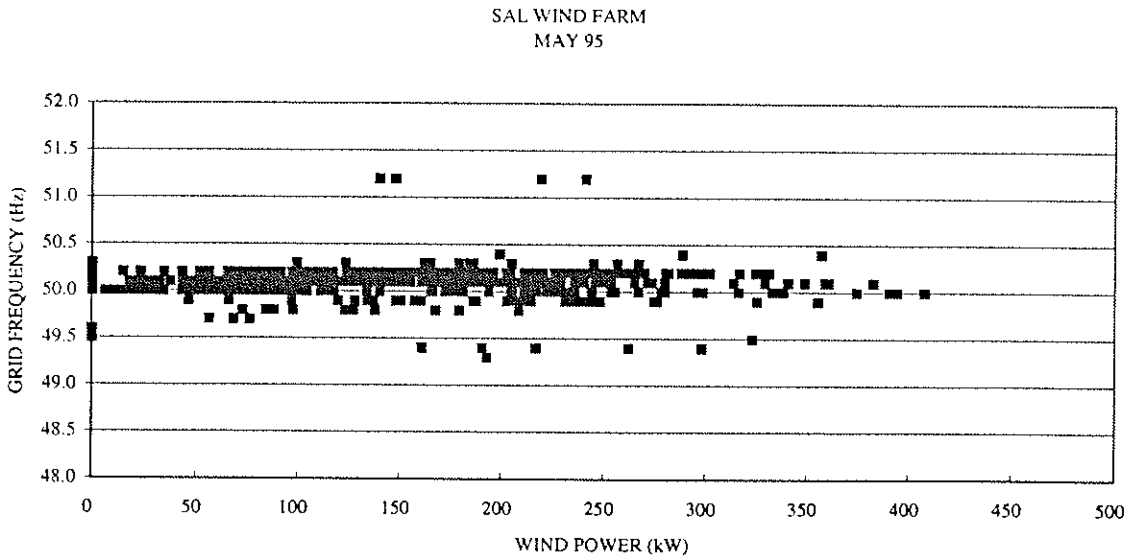


Figure 4.8 Measured instantaneous grid frequency at Sal wind farm as a function of the wind power output, May 95.



4.1.1.2 Voltage unbalance

The voltage unbalance is now reduced to an acceptable level at Sal and Mindelo, whereas in Praia the situation has become worse and is exceeding the international limits for voltage unbalance stating that during a week 95 % of the negative phase sequence (U-) should be within the range 0 to 2 % of the positive phase sequence component (U+), see CENELEC EN50160 *Voltage characteristics of electricity supplied by public distribution systems* European Committee for Electrotechnical Standardization (1995). The figure below shows the calculated 95 % fractile of the voltage unbalance for the measurements prior, during and after installation of the Step 1 wind farms. The timeseries of the voltage unbalance have been calculated as:

$$\theta = acos \frac{U_{TR}^2 + U_{ST}^2 - U_{RS}^2}{2 U_{TR} U_{ST}}$$

$$U\text{-}/U+ = \sqrt{\frac{U_{TR}^2 + U_{ST}^2 - 2 U_{TR} U_{ST} \cos(60 - \theta)}{U_{TR}^2 + U_{ST}^2 - 2 U_{TR} U_{ST} \cos(\theta + 60)}}$$

and then the 95 % fractile has been estimated as the average value plus two times the standard deviation.

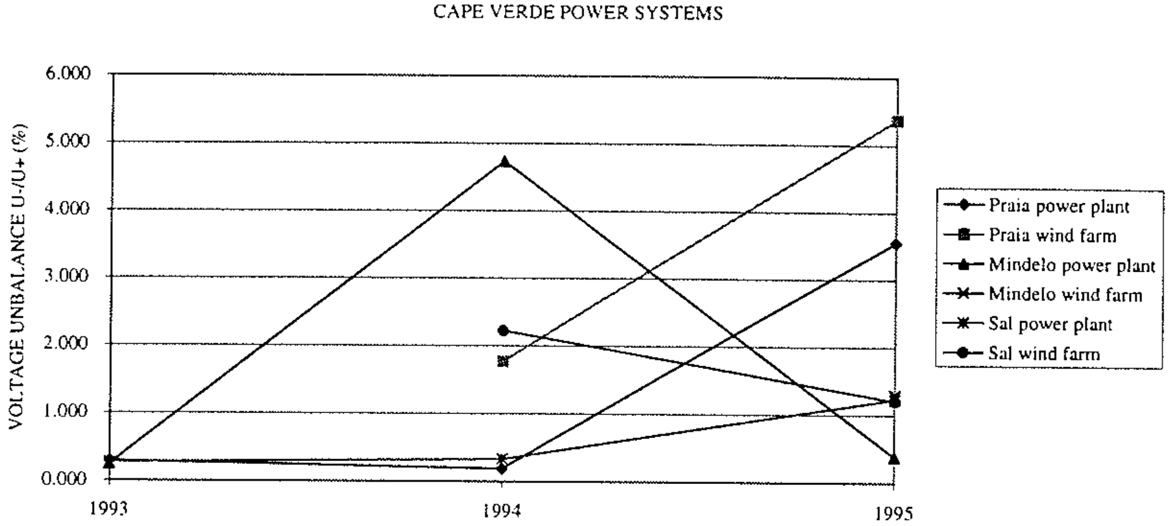
It has been investigated if the voltage unbalance is due to the wind farms.

At Sal it was observed that stopping and disconnecting the wind turbines did not significantly change the voltage unbalance neither at the power plant or at the wind farm. Thus it seems that the voltage unbalance at the wind farm is due to an unbalanced supply voltage from the power plant. The reason for the voltage unbalance at the Sal power plant can be unbalanced consumer loads and/or malfunctioning power plant voltage control.

In Mindelo the voltage unbalance observed at the power plant during Nov/Dec 94 was probably due to malfunction of the new power plant voltage control. This has now been repaired and the voltage at the power plant is now balanced. The reason for the remaining wind farm voltage unbalance is not known. It is observed however that the unbalance is not affected significantly by variations in the wind power production or stop of the wind turbines.

In Praia, where the voltage unbalance was measured to be the highest, the wind farm feeder was disconnected for a short period during 29 May 95 at the "5'th of July" sub-station as to investigate if this would change the voltage unbalance at the power plant. As can be seen from the enclosed time series plot of the measurements at Praia power plant, this did not significantly change the voltage unbalance. Thus, the voltage unbalance at Praia power plant seems to be due to unbalanced consumer loads and/or malfunctioning power plant voltage control. Like in Mindelo, there seem to be no significant correlation between the voltage unbalance at the wind farm and the wind power production. Probably the voltage unbalance at Praia wind farm can be brought down to an acceptable level similar to the level observed at Mindelo wind farm by balancing the voltage at the power plant. As the voltage unbalance at Praia power plant is exceeding international requirements, it is suggested that Electra takes action as to reduce the voltage unbalance.

Figure 4.9 Comparison of measured voltage unbalance prior, during and after commissioning of the Step 1 wind farm.



4.1.1.3 Power factor

The relation between the active output power and the reactive consumption of Mindelo wind farm is shown in figure 4.10 below. The relation is the same also for the wind farms at Sal and in Praia. It is seen that the wind farm consumes about 350 kvar at 1000 kW production, corresponding to a power factor about 0.94.

The effect of the long feeder between Mindelo power plant and the wind farm in terms of reactive production is shown in figure 4.11. Comparing figure 4.10 and 4.11, it is seen that the cable incl. transformer losses produces about 250 kvar between no load and 600 kW. At loads above 600 kW the reactive losses in the connection becomes significant and at full load (1000 kW) the net reactive production of the feeder incl. transformer losses is reduced to about 100 kvar. The resulting effect of the wind farm and cable connection seen from the power plant is thus a reactive consumption of about 250 kvar at 1000 kW output, corresponding to a power factor better than 0.97.

The effect of the cable connection between the power plant and the wind farm in Praia gives a similar improvement of the power factor. At Sal, the cable distance between the wind farm and the power plant is only 1.5 km, giving a limited power factor improvement only.

Figure 4.11 Measured relation between wind farm active output power and reactive consumption.

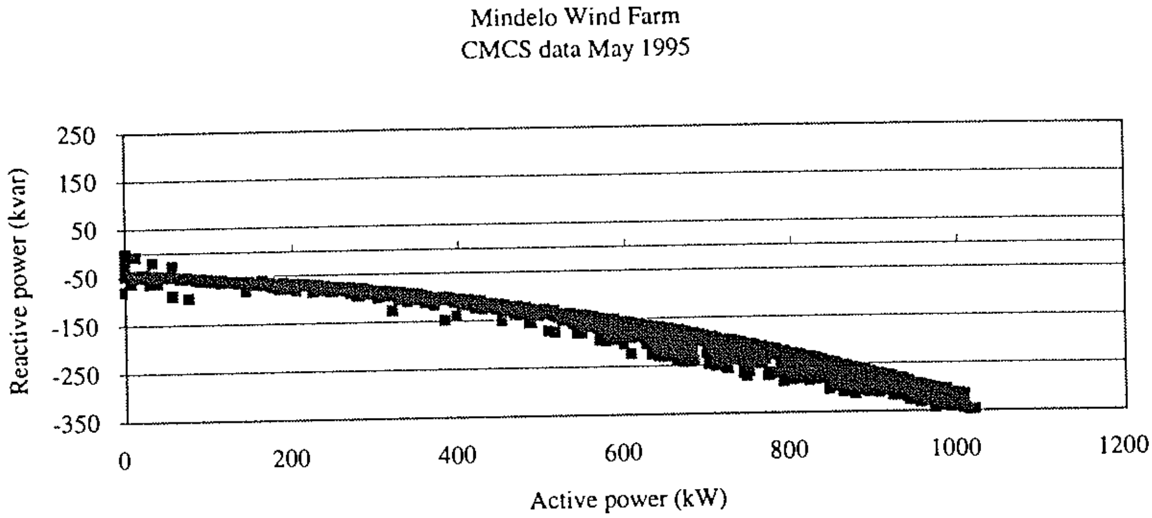
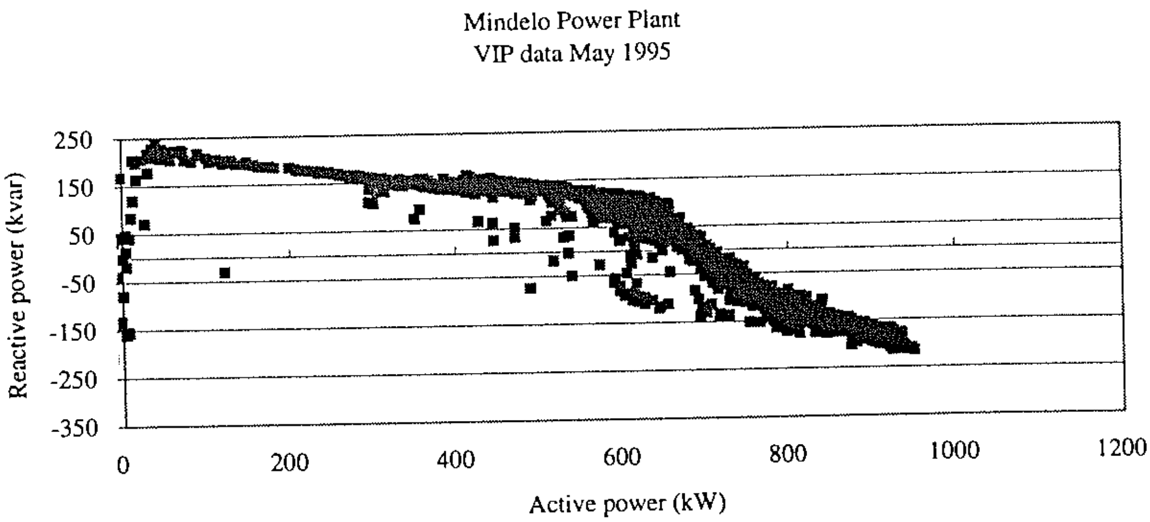


Figure 4.10 Measured relation between Mindelo wind farm (at power plant) net active output power and reactive consumption.



4.1.2 Power plant measurements

As to investigate the Step 1 wind turbines power fluctuations and impact on the power and power factor variations at the diesel power plant, measurements at the diesel power plants of Praia and Mindelo have been carried out using a PC data acquisition system. The PC data acquisition system is a part of the Step 1 wind farms electrical work shop equipment. At Sal, the PC data acquisition system was not installed as that would require significant additional hardware and man-hours compared to the installations of Praia and Mindelo.

Table 4.2 Specification of power plant measurement campaigns.

PRAIA POWER PLANT	SET UP	DATA FILES
Fri. 261193 - Sat. 271193	PRA05	PRA05_2.PRN - PRA05_28
Tue. 151194 - Wed. 161194	PRA05	PRA51.ZIP
Thu. 171194 - Fri. 181194	PRA05	PRA52.ZIP
Thu. 250595 - Fri. 260595	PRA05	PRA53.ZIP
	PRA05	PRA54.ZIP
MINDELO		
Fri. 031293 - Sat. 041293	MIN04	MIN04_2.PRN - MIN04_28.PRN
Fri. 041194 - Sat. 051194	MIN06	MIN06.ZIP
Mon. 220595 - Mon. 220595	MIN07	MIN07_19.PRN - MIN07_27.PRN

4.1.2.1 Diesel power plant load variations

Figure 4.12 and 4.13 show measured diesel power plant load variations as a function of the wind power penetration. The load variation is here given as the standard deviation of the load within a 5 minutes period in percent of the average load. The wind power penetration is the ratio between the wind power output and the total load. The measurements indicate that there is a weak correlation between the load variations at the diesel power plant and the wind power penetration. The load variations as seen from figure 4.12 and 4.13 are except for single samples between close to 0 % and less than 5 %. No sample is above 8 %. According to the enclosed communication with the diesel engine manufacturer MAK, see Appendix B, load variations less than 10 % will not affect the fuel consumption or the wear of the engines.

Figure 4.12 Measured 5 min. standard deviation of diesel load as a function of the wind power penetration (Praia power plant, 15 - 18 Nov 94).

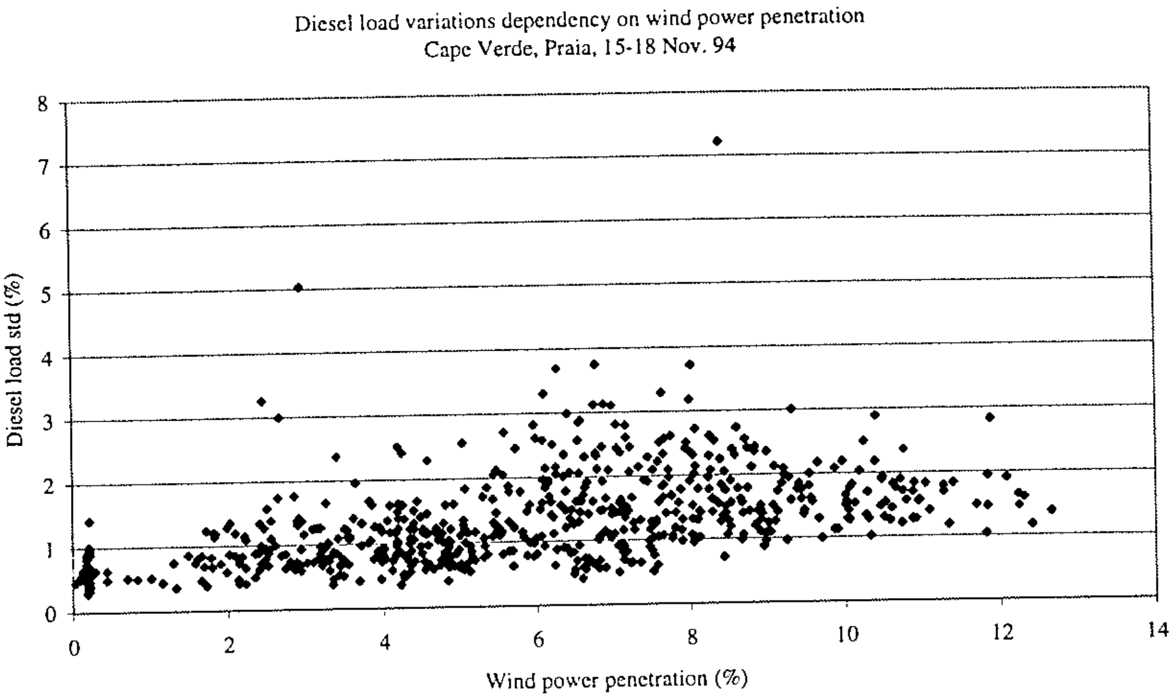
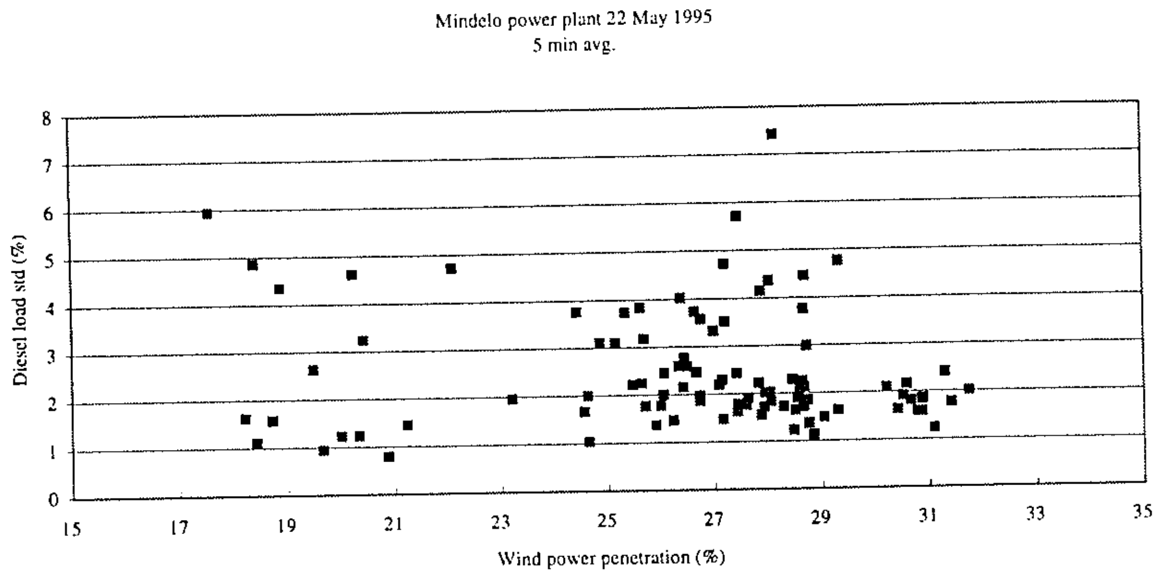


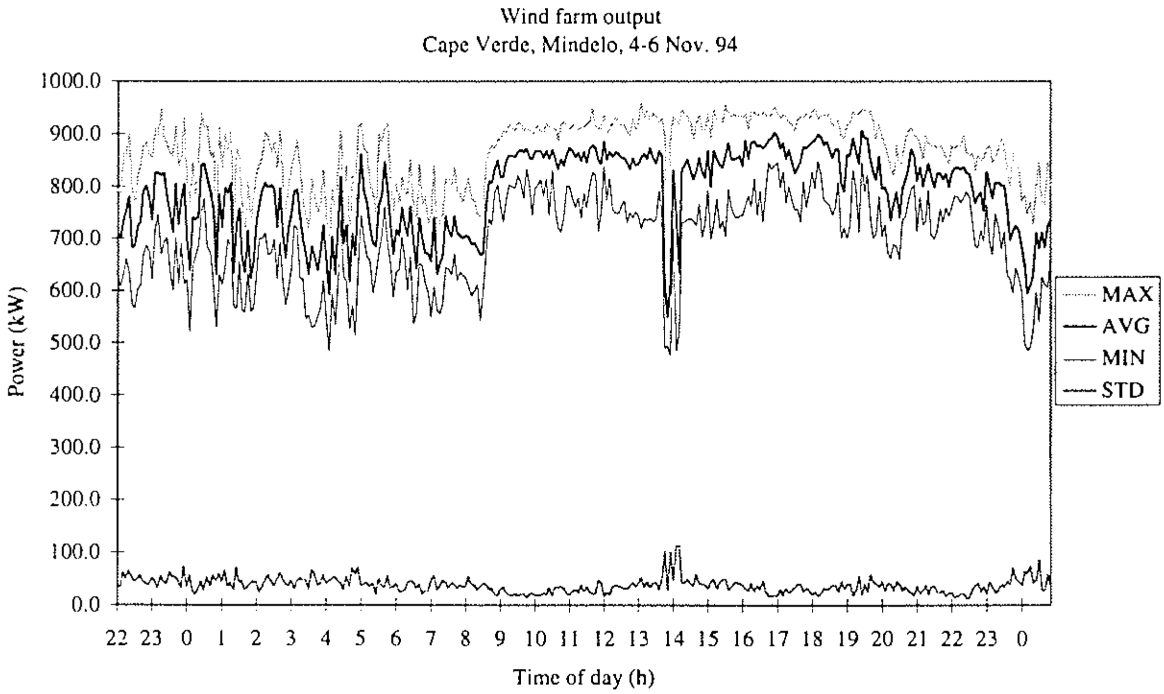
Figure 4.13 Measured 5 min. standard deviation of diesel load as a function of the wind power penetration (Mindelo power plant 22 May 1995).



4.1.2.2 Wind power fluctuations

Using a intermediate connection of the PC data acquisition system, 1 Hz measurements of the wind power production at the wind farm feeder at Mindelo power plant were taken during a measurement campaign in November 1994. Figure 4.14 shows the measured wind power output. The figure shows that the wind power production from Mindelo wind farm during this 28 hour period is fairly stable.

Figure 4.14 Timeseries plot of measured power output from Mindelo Step 1 wind farm, 4-6 Nov. 94. Max. and min. values are 1 Hz samples, avg. is 5 minutes averages, std. is standard deviation within 5 minutes.



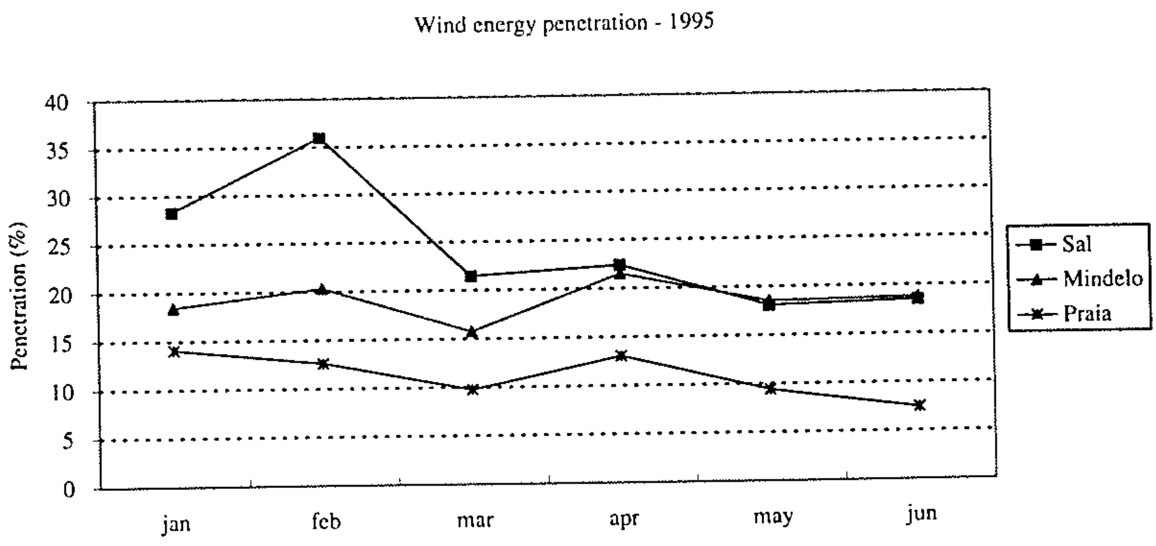
4.2 Power system operation with Step 1 wind turbines

The average wind energy penetration for Jan-Jun 1995 is totally for the three power systems 16%. The monthly average wind energy penetration levels provided by the wind farms are shown in Fig. 4.15.

It should be noted that the 36% wind energy penetration at Sal in Feb 1996 was obtained by manual wind farm control, exercised by the diesel power plant operators using the remote stop facility of the two wind turbines. No technical problems and black-outs were encountered.

The difficulty at this high wind energy penetration is to ensure sufficient spinning capacity on the diesels and at the same time run them at a sufficient load to avoid soiling, i.e. a certain minimum load is required on the spinning engines. The operators therefore have to start and stop engines depending on the wind. It seems that operators at Sal quickly have developed an eye for predicting drops in the wind speed, which is both due to their skill and interest in the technology, but also because the winds are very steady. The scale and shape parameters (A, k) of the Weibull distribution fitted to the wind data measured at 30 m agl in Feb 95 at Sal were: (10.1, 4.63). A high shape parameter means steady wind, which in turn means steady wind power production and thus a high capacity value of the wind turbines producing a reliable power which to a certain degree can be used as firm power by skilled operators.

Figure 4.15 Month by month wind energy penetration Jan- Jun 95.



4.3 Fuel savings

Actual fuel savings obtained due to wind energy production cannot be measured directly - estimates have to be made.

Fuel flow-meeters are not available at the power stations. Data are thus not available for detailed analyses of the specific fuel consumption's dependency on load fluctuations caused by the wind power. In general, fuel savings due to wind energy can be estimated by simulating the power system operation without wind power as to find the "no wind" fuel consumption, and then deduct the savings as the difference between the "no wind" fuel consumption and the actual fuel consumption for the time period of question. Such a procedure would require detailed input data and time consuming computer simulations. Estimates of fuel savings due to the wind energy production therefore have been made month by month for each of the diesel gensets, basically by

a) determining the actual average specific fuel consumption of the genset
b) finding the additional production that would have been necessary if there was no wind power
c) adjusting the specific fuel consumption of the genset to an improved efficiency corresponding to the increased average load, which is done by a linear approximation using the slope of the specific fuel consumption curve at normal operation as given by the technical specifications of the genset.

The procedure for estimating the fuel savings due to the Step 1 wind turbines on a monthly basis has been discussed with Electra in Praia, Mindelo and Sal. The procedure utilizes the recorded monthly total load, the wind energy production and the gas oil and heavy fuel consumption as input data for calculating the fuel savings. The procedure for estimating the fuel savings due to the Step 1 wind turbines has been implemented as a Q-pro spread-sheet and handed over to Electra. The procedure and the applied formulas in the spread-sheet are further described in appendix C.

In relation to the fuel savings calculations for Praia, Mindelo and Sal due to the Step 1 wind farms, it should be noted that the α parameter will be different for different diesel generator sets. For these calculations however, the α parameter is pragmatically set to 0.1 % for both Praia, Mindelo and Sal, i.e slightly higher (worse) than α = 0.06 % for the new Mindelo diesel generator sets.

Fuel savings have lead to an actual decrease in cost of electricity as shown in Fig. 4.16, illustrating the decrease by showing the average monthly fuel expenses in ECV per kWh supplied to the consumers for the period Jan 1994 - Jun 1995. It should be mentioned that a part of the decrease in Mindelo is due to the practically simultaneous start-up of the wind farm and a new diesel power station.

When comparing fuel savings and wind energy penetration, it is seen that the reduction in fuel expenses directly depends on the amount of wind energy supplied in the month, although other factors also play a role. The dependency on wind energy production is clearly seen when plotting the monthly average fuel expenses vs. the monthly average wind energy penetration, as e.g. done for Sal for the period January 1994 to June 1995 in Fig. 4.17.

Further details on the power system operation and fuel savings due to the Step 1 wind farms can be read from the spread-sheet printouts in Appendix C.

Figure 4.16 Monthly system fuel expenses in Cape Verde escudos (ECV) per kWh supplied.

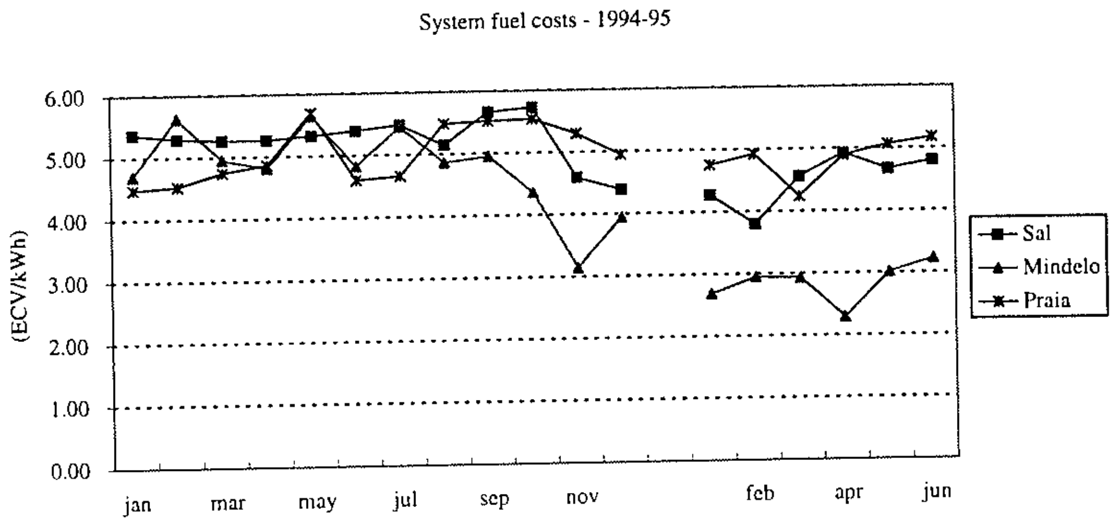
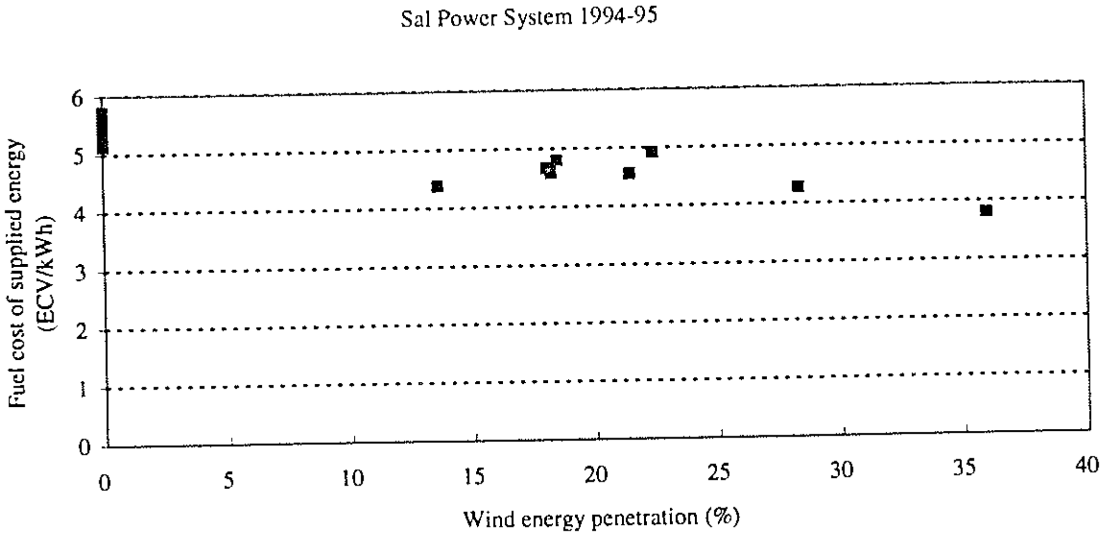


Figure 4.17 Monthly system fuel expenses in Cape Verde escudos (ECV) per kWh supplied plotted versus the wind energy penetration at Sal.



5. Institutional analysis of the power sector

The electric power supply of the main demand areas of the Republic of Cape Verde - Praia, Sao Vicente and Sal - is undertaken by the national power company, ELECTRA[1]. ELECTRA is also responsible for the water supply. The responsibilities for the supply of electricity and water range all the way from design and construction of plants to purchase of fuels, operation of plants, production and distribution of electricity and water to each consumer.

ELECTRA is a public company with its head quarters in Mindelo, with subsidiaries (Delegations) in Sal, Sao Vicente, and in Praia. The Delegations are responsible for the operation of their area and reports to the main office, this includes the operation of the wind farms.

The Step 1 Wind Farm project was implemented by ELECTRA and it is assumed that a Step 2 Wind Farm project would be so too. This institutional analysis therefore concentrates on the present and possible future institutional situation for ELECTRA in the power sector of Cape Verde.

5.1 Ownership of the wind turbines

Wind farms on ELECTRA power systems are considered ELECTRA investments, even in the case of the Step 1 wind farms, which were given as a grant from the Danish Government to the Government of Cape Verde, and then in turn transferred to ELECTRA on on-lending terms. The implication of the method of transferring the ownership is dealt with later.

5.2 Recipient of benefits from the wind farms

The recipient of the benefits of the production from the wind farms is the ELECTRA company. The management of ELECTRA express awareness of the fuel savings due to the Step 1 Wind Farms and do appreciate these savings. The Government, responsible for the appropriation to ELECTRA to cover the financial deficit, unfortunately also are aware of the savings, and the appropriations reflected this situation with cuts in the appropriations of the same size as the fuel savings.

The result for ELECTRA is that the financial constraints are unchanged, but now ELECTRA has the responsibility to operate and maintain the wind turbines in order not to increase the financial constraints.

From the fiscal year 1996 a new accounting system has been implemented. The new system is along the line of visualizing the benefits and costs of the operations of the company and consequently also the losses and the gains of different activities. The wind farms will occur as a separate unit with its own budget. At the time before implementation of the new system, it was not known if the budget for the wind farms was to include accumulation of budget for the major

[1] Empresa Pública de Electricidade e Água

overhauls of the wind turbines to be anticipated after 10 years of operation. The budgets for the operation and maintenance of the wind turbines were not yet decided. It is recommended to keep separate budgets for each wind farm.

What is more important for the operation and maintenance is that there was no decision if the units responsible for the wind farms were allowed foreign currency for the purchase of spare parts. If the unit has to apply for the funds for spare parts, the interruption of the production from break down of a simple spare part could be long and the value of the loss of production exceeding the spare part many times.

5.3 Reorganization of ELECTRA

The present organization of ELECTRA is subject for discussions. A study undertaken by the Capeverdean Committee for Privatization (GARSE) assisted by EDF has analyzed the possibilities, and five scenarios have been described. For the further political discussions and decision three scenarios will be subject for detailed political treatment.

The main problems for ELECTRA to be solved are the strongly regulated conditions for operation, including regulations of prices of fuel and regulations on tariffs of sales, along with a heavy burden from the governmental loans. The present financial situation for ELECTRA does not allow for generating a cash flow income from sales, able to match the costs of running the company.

The most likely scenarios for the further political discussions of restructuring ELECTRA are:

- Splitting ELECTRA into two independent companies, one responsible for the water production and distribution, and one responsible for the production and distribution of electricity.
- Splitting ELECTRA into independent companies responsible for the operation on each island.
- To keep ELECTRA as an integrated company as it is known today, but as a partly privatized company.

Each scenario includes the option of full or partial privatization. Any privatization of ELECTRA must be accompanied with means of bringing ELECTRA in a position to be able to survive financially or even better to generate a profit. To build confidence to such an ability, it is suggested to remit some of the debt of ELECTRA of some specific assets.

For this study it is assumed that the Step 2 wind farms are to be part of the unit responsible producing electricity. Further it is assumed that any reorganization and/or privatization of ELECTRA does not influence the operation and maintenance of the wind farms in any negative way. On the contrary the opportunity to generate a profit and any degree of privatization, puts the pressure on the company to produce as much as possible on the wind turbines in order to earn a profit. The pressure on the company arises from the accountant point of view, that wind turbines apply electricity using a very low amount of running costs compared to generation of electricity using fuel. Once the investment has been made, the more electricity generated from the wind farms the higher profit for the company and the share holders.

Even if the reorganization of ELECTRA does not include privatization, the financial reorganization of the company will impose the same incentives to maximize the production from the wind farms.

In the case of ELECTRA, the concept of privatization and the policy of utilizing the local energy sources works together.

5.4 Organizational responsibility

At present, the exact organizational responsibility for the wind farms in a reorganized ELECTRA is unknown. The responsibilities for the wind farms have formally been handed over to the Technical Department and Delegations of each island. Still the wind farm at Mindelo seems to be too close to the implementation unit of ELECTRA, DEP, and the power station is hesitating to take full responsibility. Also, the integration of the operation of the wind farms to the daily operations varies for the three islands.

At Sal the wind farm is operated as an integrated part of the system, and the equipment is regarded equal to the other production facilities. At Praia the turbines are less visible in the power system and the integration is not as far as on Sal. In Mindelo the integration is low due to two reasons, one that the implementation unit of ELECTRA still are responsible for any practical matter and two, because the wind farm is regarded as an external element of the production facilities and are demanding a different approach to operation of the diesel generators.

On Sao Vicente and on Sal the wind energy input is quite visible in the statistics. The savings of fuel and the contribution of the wind turbines are recognized by the system operators, especially on Sal. In Praia, the contributions of the wind turbines are less visible in the statistical figures, and the awareness of the wind turbines are obviously lower than on the other islands.

It seems that the higher the penetration level of wind energy and the further the distance to those who hand over the responsibility, the easier the integration of the wind farms. Furthermore, the awareness in ELECTRA of the importance of the wind farms is to a certain degree proportional to the contribution of the wind farm to the total electricity consumption. Step 2 will increase the awareness of the organization and the status of the organizational body and staff responsible will enjoy a higher degree of respect.

Any future development in the wind farms and the penetration level is assumed to make it easier for the responsible units to integrate new technology. Further, any privatization and/or reorganization will impose the incentive of maximum production from the wind farms.

The implementation unit of the wind farms are the Engineering Department and when ready for operation the Technical Department and ELECTRA Delegations take over the responsibility for operating the wind turbines. In the Step 1 wind farms, a special organizational body of the local delegation of ELECTRA is responsible for the operation and maintenance of the wind farms.

This organization will be appropriate for Step 2 as well and by the time of the implementation of Step 2, the organization will have been functioning for 2-3 years and a considerable amount of experience has been gathered.

6. Energy policies and plans

No specific plans for the energy sector have been issued since the "Development Strategies and Policies, 1992 -1995" was issued for the Geneva round table conference in 1992. The strategy and policy statements were made in a general form and are still operational and valid.

The energy policy of the Government has changed only marginally to a policy that to an even higher degree underlines the importance of utilising the energy resources available on Cape Verde and to develop means of producing from the natural resources. This was also strongly expressed in the Round Table strategies and policies, and as the statements show, the efforts to realize the policy also become visible.

Among the means of producing electricity from local resources are the wind turbines already in operation.

The investments in wind turbines are treated no different from investments in conventional capacity. The policy is to transfer the ownership and the investments and by this the capital costs to the recipient institution, ELECTRA.

The policy for the electricity sector is to develop the industrial sector, by securing access to electricity at reasonable prices, and to facilitate development of the standard of living by providing access to electricity for private consumers. The extension of the grid for supplying the private consumers at the same time opens for efficient supply for small scale industries, workshops, tradesmen, etc.

6.1 Legislation

ELECTRA is a state owned company operating and managing the electricity supply for the Praia area, Mindelo, Sal, and Boa Vista. The areas are separated and there are no plans for connecting the islands electrical.

It is expected that ELECTRA might be privatized in the near future, either as separate electricity and water companies or as separate companies supplying electricity and water for each of the four areas.

Before any privatisation a legislation must be applied. The legislation should regulate the conditions for the company/companies. Presently, all of the privatization scenarios considered recommend that the wind farms remain an integral part of the electricity producing company.

Special legislation would be required if private investors (other than ELECTRA) should be permitted generating electricity for feeding and selling it to the public grid, which would be the interest of private investors in wind farms.

6.2 Subsidies, pricing and tariffs

Two types of Government subsidies of electricity and water production exists:

- subsidy of fuel for electricity production
- payment of ELECTRA's financial deficits

The Government subsidies are, partly fianced by duty on fuels and gasolin for transportation, partly by the fact that some ELECTRA investments are financed by foreign grants to the Government. Regardless of the way of financing the subsidy, the Government of Cape Verde is to appropriate funds for the electricity and water sector at the expense of other sectors.

The pricing of the electricity is p.t. decided by the Government. The tariffs are fixed by the Government and so are the prices to be paid for the fuel. The complicated pricing of the fuel may not be possible if ELECTRA privatized. Therefore, subsidies are assumed to be removed. No subsidies are anticipated beyond year 2000.

The tariffs of the different categories for consumption also show some subsidising of the electricity production, which is introduced to the system by imposing a higher price to be paid for the public consumption. The tariffs for the commercial use are 11.68 ECV/kWh and 14.98 ECV/kWh. The subsidizing from the tariff is not as high as the subsidy for fuel. The tariff for the 5 % share of public use of electricity is approximately 30 % higher.

7. Power system development plans and forecasts

It has been agreed that the Feasibility Study for Step 2 Wind Farms will analyze two different development scenarios for the power sector regarding consumer loads, grid connected desalination plants and diesel power plants capacity.

The two scenarios for the development within the analysis period of 20 years can briefly be defined as follows:

- Scenario A:
  A scenario assuming continued economic growth, which for Mindelo and Sal is determined in accordance with the Master Plan /6/ (prepared in cooperation with the World Bank) - except for minor agreed upon modifications, and which for Praia is adjusted relative to the Master Plan in accordance with the newer EDF study /7/ "scenario 1" suggestions for Praia.
- Scenario B:
  A scenario originally recommended by the DANIDA Project Review, September 1994, /8/ aiming at a conservative determination of the amount of wind power capacity to be installed in a Step 2. This scenario assumes a development in consumer loads identical to that of Scenario A except for the desalination loads. The desalination capacity and loads assumed is in this scenario limited to the amount installed by the first year of operation of the Step 2 Wind Farms (1998) for which firm plans exist. The development in diesel power plant capacity is reduced correspondingly, due to the reduced needs for diesel capacity according to this scenario.

The sub-sequent sections give further details on the assumed development scenarios in terms of annual consumer loads, grid connected desalination plants and diesel capacity.

7.1 Load and desalination forecast

Hour by hour variations as well as seasonal variations are analyzed using readings of actual hour by hour consumer and desalination loads from Electra power plant logbooks in 1991, 1992 and 1993. The data analysis indicate that the desalination load may be considered to be constant over the year, whereas the consumer loads for each of the power systems can be described by eight 24 hour consumer load patterns, i.e. one week-day and one weekend-day pattern for each of the four seasons of the year. The assumed load patterns excluding desalination loads are shown in Figs. 7.1-7.6. Actual numbers are found as part of WINSYS power system model inputs in Appendix I, J and K.

The forecasts of the daily load patterns are estimated assuming normal operation only. The calculated load profiles thus differ from the profiles as they may appear from the annual reports of ELECTRA because these may include also not normal operational conditions.

ELECTRA is responsible for supplying fresh water from desalination of sea-water. As can be seen from Section 2, ELECTRA p.t. operates a range of different desalination plant types. Future desalination plants are however planned to be Mechanical Vapor Compressor (MVC) types only. These will be grid connected, and is for the propose of this load forecast assumed to consume about 10 to 12 kWh of electricity per m3 of fresh water output.

Figure 7.1

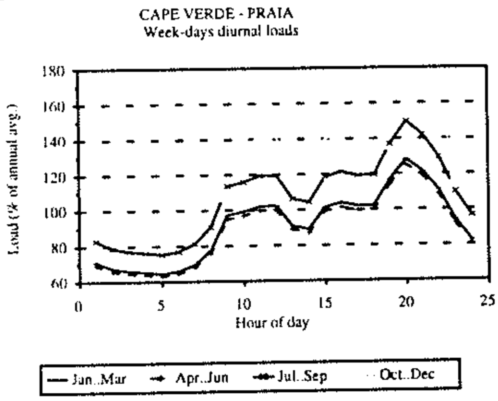


Figure 7.2

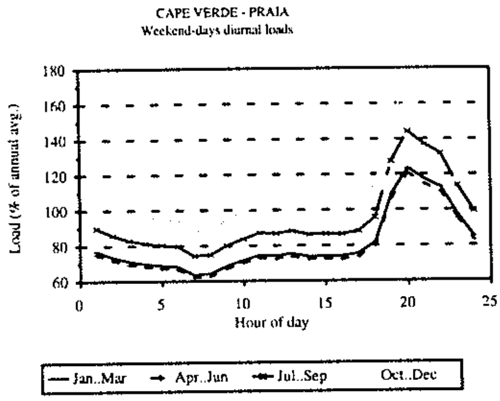


Figure 7.3

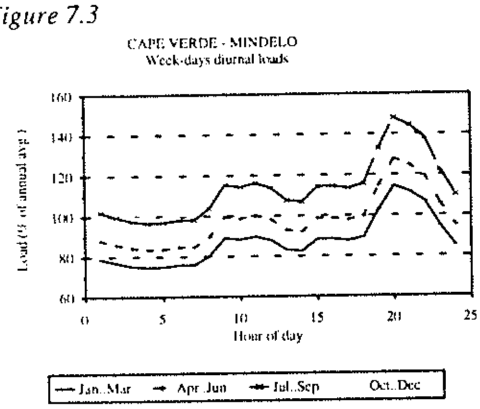


Figure 7.4

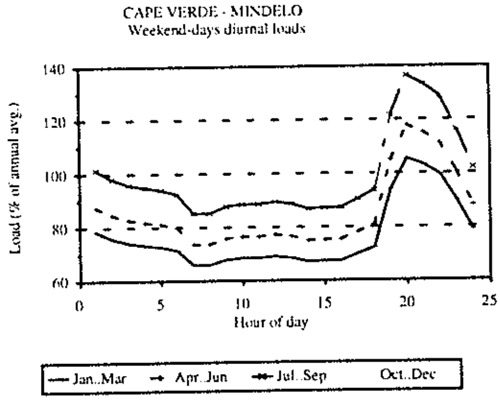


Figure 7.5

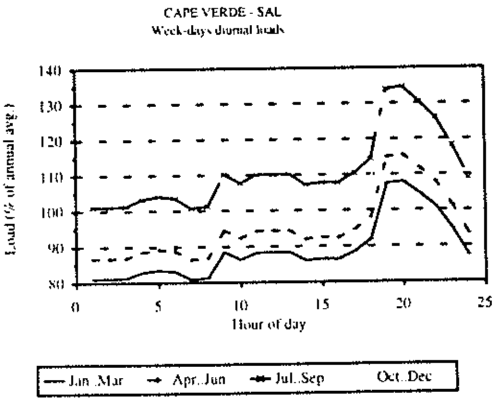
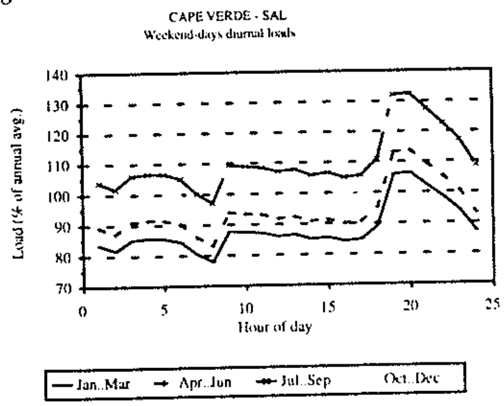


Figure 7.6



The following two sub-sections give further details for Scenario A and B load and desalination forecast. Regarding demographic indicators, development in population and demand for electricity, these subjects are treated in Appendix D.

7.1.1 Scenario A

The scenario assumes continued economic growth, which for Mindelo and Sal is determined in accordance with the Master Plan (prepared in cooperation with the World Bank) - except for with ELECTRA minor agreed upon modifications, and which for Praia is adjusted relative to the Master Plan in accordance with the newer EDF study "scenario 1" suggestions for Praia.

7.1.1.1 Praia

Praia is the capital of Cape Verde and the largest city in Cape Verde. About 24 % of the Cape Verde population lives in Praia. The population of Praia is expected to continue growing partly due to migration of people from other parts of Cape Verde, partly due to birth rate, and partly due to that the immigration to other countries has been more difficult during recent years. The potential for growth in the population is very large and so is the potential for growth in the electricity consumption.

During recent years the consumption of electricity for the residential sector has increased rapidly and so has the consumption for public lighting, trade, and service sector. The consumption of the industrial sector has only increased very little, but is expected to reach a higher growth rate during 1996 and onwards.

The assumed consumers load forecast is equal to the revised forecast of the Master Plan, i.e. EDF forecast "scenario 1" modified slightly upwards to reach the actual values of 1994. This implies that the EDF forecast has been added 600 MWh of consumption from year 1994 and all the following years.

Pt. the demand for electricity is higher than the supply capacity. This has resulted in frequent load sheddings (disconnection of certain feeders) disconnecting groups of consumers as well as delays in connecting new consumers to the grid. The planned near future installation of additional diesel capacity as described in Section 7.2 aims at meeting the demand for electricity and to avoid frequent load sheedings.

Natural fresh water resources has till recently been the only fresh water source for Praia. The natural resources are however limited and suffers from salt water penetration, and just recently (late 1995) a sea water desalination plant consisting of two MVC 1200 m^3/day units has been installed in Praia as to support the supply of fresh water. Future units are assumed to be installed in accordance with the EDF forecast. Based on discussions with ELECTRA, the MVC units are assumed to be operated on 50 % load until 1998, and after on 75 % load.

Fig. 7.7 shows the forecasted annual consumer loads, desalination load and total sum of consumer and desalination loads. Fig. 7.10 shows the corresponding maximum and minimum loads. Actual numbers are found as part of WINSYS power system model inputs in Appendix I.1.

7.1.1.2 Mindelo

Mindelo at Sao Vincente is the second largest city of Cape Verde. About 15 % of the Cape Verde population lives in Mindelo.

The forecast of consumers loads is based on the Master Plan "high scenario" up to 1998, and from 1999 and onwards on the Master Plan "low scenario".

Re. desalination load, the existing desalination plants with internal electricity generation capacity are assumed not to supply energy to the grid or demand energy from the grid. Thus, only the MVC units are assumed to load the grid. The installation of new MVC plants are assumed in accordance with the Master Plan with minor modifications agreed with ELECTRA. Further, based on discussions with ELECTRA the MVC plants are assumed to be operated at 75 % load.

Fig. 7.8 shows the forecasted annual consumer loads, desalination load and total sum of consumer and desalination loads. Fig. 7.11 shows the corresponding maximum and minimum loads. Actual numbers are found as part of WINSYS power system model inputs in Appendix J.1.

7.1.1.3 Sal

About 2 % of the Cape Verdian population lives at Sal. Sal houses the largest airport in Cape Verde and significant tourist activities.

The demand for electricity on the ELECTRA power system depends very much on the future of the international airport and the development in the tourist activities. The Airport could become a major consumer, but is p.t. only partly connected. The tourist activities have an opportunity to increase. A new hotel is under construction and will soon be ready for use. The tourist activities are planned to expand, but the potential of the tourist activities is uncertain.

Fig. 7.9 shows the forecasted annual consumer loads, desalination load and total sum of consumer and desalination loads. Fig. 7.12 shows the corresponding maximum and minimum loads. Actual numbers are found as part of WINSYS power system model inputs in Appendix K.1.

7.1.2 Scenario B

The DANIDA Review Mission recommended "to use the Master Plan "Low"-forecast plus load from present and firmly decided desalination plants when the level of wind energy penetration is considered....."

The DANIDA Review recommendation was relevant based on the figures available at the time, but development in electricity generation capacity, desalination capacity, and consumption has outdated the Master Plan "Low"- forecast. To meet the requirements of the Review Mission a load forecast based on the firmly decided increase in capacity for desalination and supply of electricity combined with the demand forecast of ELECTRA and the revised Master Plan, to the end of 1998 will be applied. For the years following 1998 the scenario assumes no increase in capacity for desalination.

Figs. 7.13 - 7.15 show the forecasted annual consumer loads, desalination load and total sum of consumer and desalination loads. Figs. 7.16 - 7.18 show the corresponding maximum and minimum loads. Actual numbers are found as part of WINSYS power system model inputs in Appendix I.2, J.2 and K.2.

7.2 Diesel capacity forecast

The development in diesel capacity for meeting the demand for electricity according to the assumed load forecasts is forecasted for Scenario A based on discussions with ELECTRA as well as suggestions from the Master Plan and the newer EDF study.

Figs. 7.19 - 7.21 show the forecasted diesel capacity development together with the estimated maximum load including desalination. Actual numbers are found as part of WINSYS power system model inputs in Appendix I.1, J.1 and K.1.

As Scenario B assumes a development in desalination loads limited to the amount installed by the first year of operation of the Step 2 Wind Farms (1998) for which firm plans exist, the forecasted development in diesel power plant capacity is reduced correspondingly.

Figs. 7.22 - 7.24 show the forecasted diesel capacity development together with the estimated maximum load including desalination. Actual numbers are found as part of WINSYS power system model inputs in Appendix I.2, J.2 and K.2.

Figure 7.7

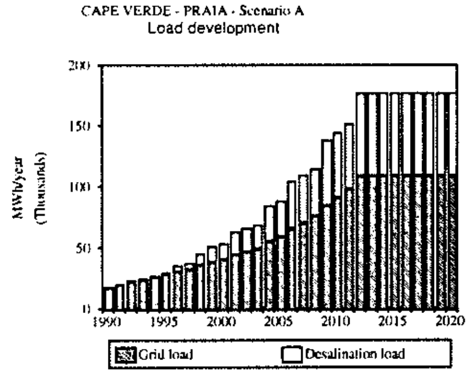
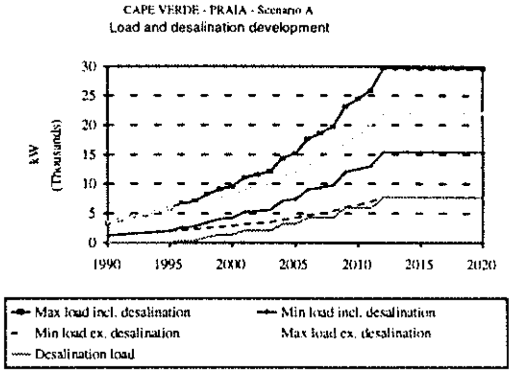


Figure 7.10



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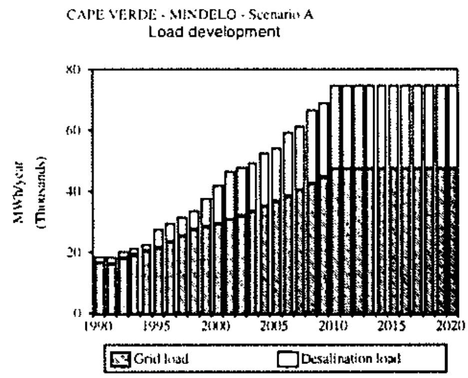

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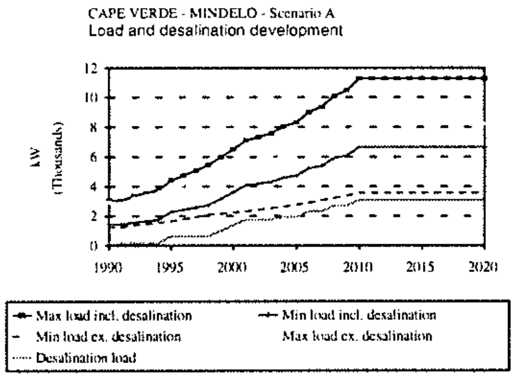

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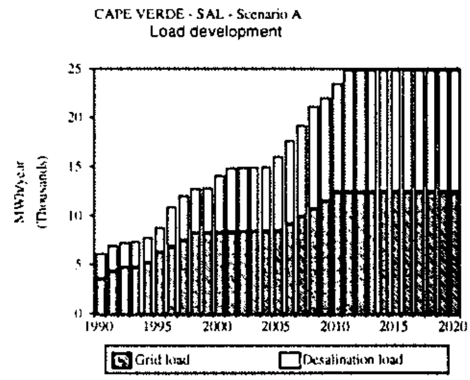
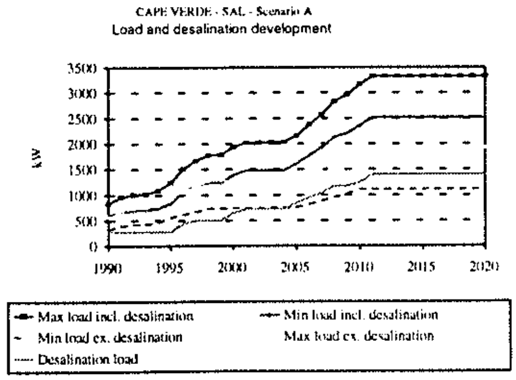


Figure 7.12



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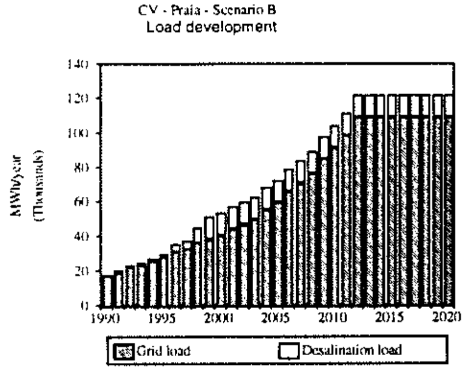

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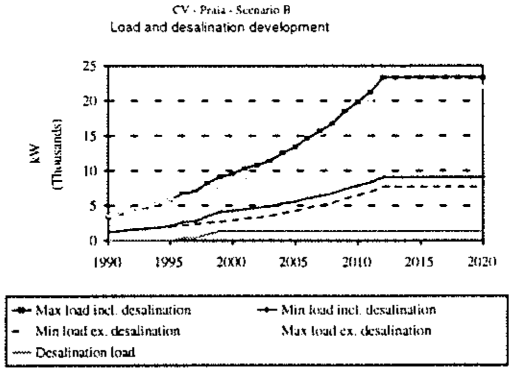

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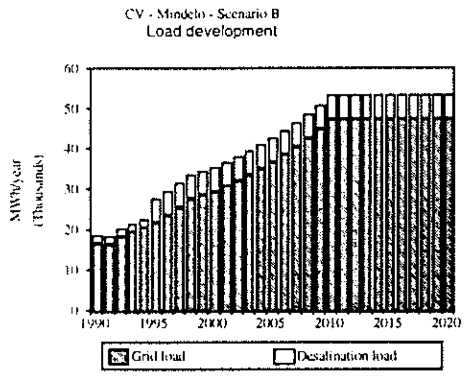

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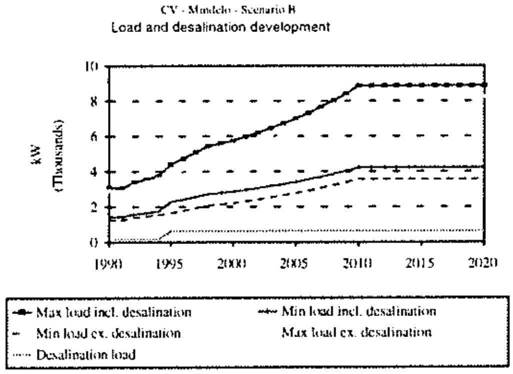

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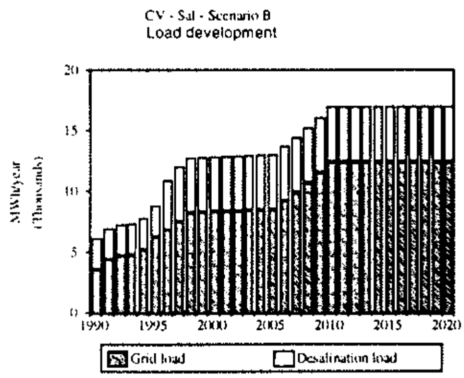

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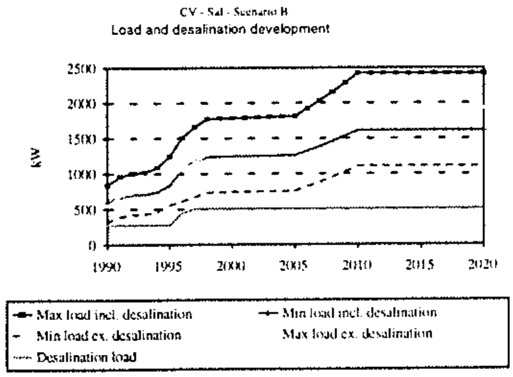

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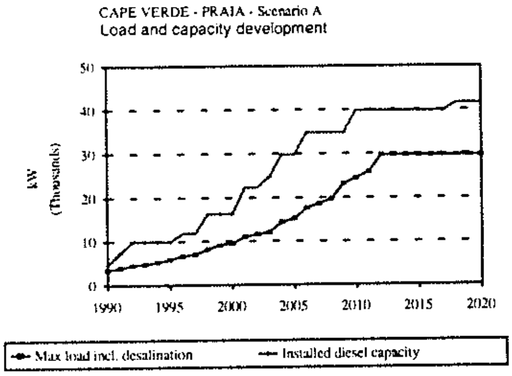

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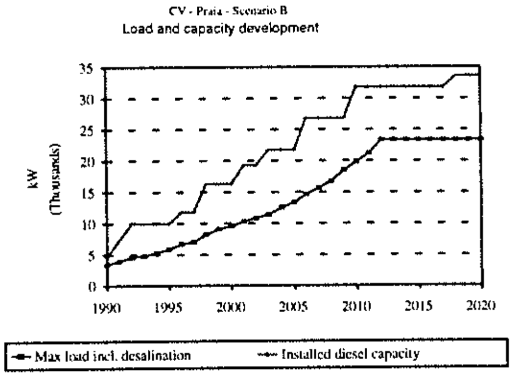

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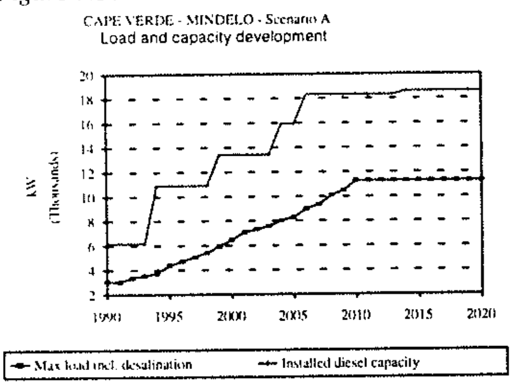
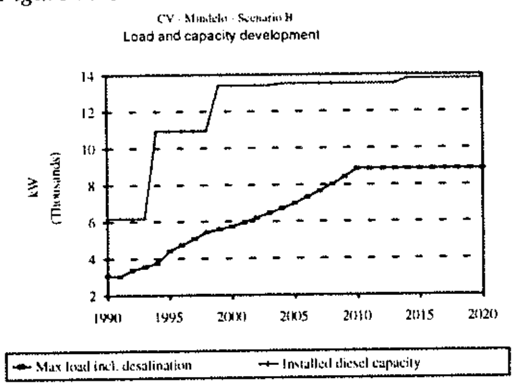


Figure 7.23



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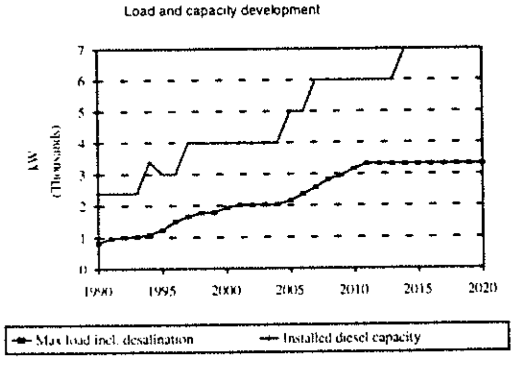
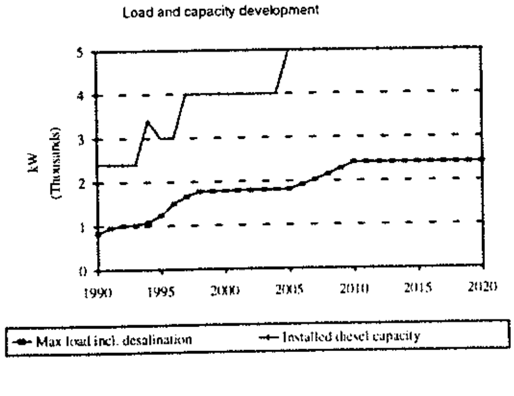


Figure 7.24



8. Wind farm siting and layout

8.1 Methodology

A site selection procedure should typically involve identification of candidate sites, sketch design of possible wind farms at the candidate sites and finally an evaluation according to selected criteria.

The three main steps in the procedure would in general normally involve:

A *Identification of a few candidate sites with best prospects regarding:*

- Availability of land, human resources and infrastructure
- Wind resources
- Power system interconnection and operation
- Adaptation to the national and local development and physical surroundings
- Suitability for project objectives

B *Sketch design and analyses at candidate sites - including relevant issues such as:*

- Wind resources and physical characteristics - data, extrapolation, analyses, statistics
- Wind turbine structural loading and safety - standards and requirements
- Wind turbines - types, sizes and design
- Electricity demand and load forecasts
- Wind farm sizing and power system configuration
- Wind farm layout
- Wind farm energy production estimation
- Electric grid connection - standards, requirements and optimization
- Power system operation and control system communication
- Environmental impact - visual, noise, wildlife, fuel savings, emissions (CO_2, NO_X, SO_2,...)
- Physical planning - existing and new requirements for the site and surrounding land
- Requirements in general of nearby installations - e.g. airports' obstacle limits
- Electromagnetic interference - e.g. airports' ILS and radio systems, LORAN and VOR systems, SOLAS systems, Microwave links, telecom stations, military installations
- Climate in general - temperature, humidity, etc., and its impact on design requirements e.g. regarding corrosion protection, cooling, tropicalization, etc.
- Soil conditions
- Access to site
- Erection - facilities, conditions, need for landscaping
- Operation and Maintenance

C *Evaluation of candidate sites:*

- Compatibility with project objectives
- Local physical planning aspects
- Potential energy production from wind farm
- Environmental impact
- Economic and financial consequences
- Sustainability of the project
- Project risks and uncertainties

In principle from the above, the entire set of analyses have to be carried out for several candidate sites for wind farms. In most cases, however, the comparison of candidate sites does not require the full detailed analysis of all aspects mentioned above. Conclusions regarding site selection is drawn from a subset of criteria and analyses sufficient for the relative comparison between sites. The sketch design and feasibility study is subsequently completed for the selected wind farm site.

8.2 Land availability

Due to the dry climate, large parts of Cape Verde is barren land with little vegetation. Furthermore, the density of habitation is very low outside towns and the few agricultural areas in valleys, mountain slopes or irrigated areas. Praia, Mindelo and Palmeira (Sal) are all surrounded by such areas of land offering itself to wind farms with little vegetation and no buildings.

Wind farm sites must be chosen as the most attractive from the evaluation criteria mentioned in section 8.1 with the best possible cost-benefit ratio and sufficiently far from the town not to interfere with any possible future town development for at least 20 years.

Such areas of land have already been identified and analyzed in the feasibility study for the Step 1 Wind Farms. At that time the sites were chosen also with a view to the possibilities for future expansion of the wind farms. Site conditions for wind farms have proven favorable at the Step 1 Wind Farms, and land for expansion of the Step 1 Wind Farms is still unoccupied. All in all, availability of suitable land seems not to be the limiting factor for expansion of the wind farm capacities at Praia, Mindelo and Sal.

The question of land ownership seems not yet completely solved, and the possible cost of land is not exactly known for Praia and Mindelo. The status for the Step 1 Wind Farms is as follows:

Praia

DGIE has received a letter from Praia municipality ensuring that the land can be given to DGIE/ELECTRA, but at an in-kind cost in free electricity to the municipality to be negotiated. According to the director of planning in Praia, the entire plateau of Mt. St. Filipe has been reserved for wind farms. This is said to be shown in the maps of the physical planning department of Praia (copy has though not been presented to the feasibility study). ELECTRA should take action to finalize an agreement with Praia municipality.

Mindelo

The land ownership question for the Step 1 Wind Farms at Mindelo has not yet been resolved. The mayor of S. Vicente expressed in a meeting with ELECTRA and the feasibility study mission team 15Sep95 that land at the Step 1 Wind Farm is the property of the municipality and can be handed over to ELECTRA. The mayor furthermore ensured that land for Step 2 e.g. on the eastern slopes of Mte. Montona will be made available by the municipality. It has been agreed that ELECTRA will take action as soon as possible to finalize a written agreement with S. Vicente municipality either as rental agreement or as actual acquisition of the land ownership primarily for Step 1, but also for the area for future possible Step 2 expansion.

Sal

The land for Step 1 and 2 wind farms at Palmeira has been given to DGIE free of charge decided unanimously at a meeting 01Aug95 in the board of the municipality of Sal (see letter to DGIE dated 22Aug95). At the meeting with the mayor, he repeated the municipality's interest in a Step 2 as well as ensured that the indicated areas for expansion will not interfere with any expansion plans for Palmeira.

The feasibility study strongly recommends that agreements with the municipalities of Praia and S. Vicente are finalized, making necessary reservations and restrictions in use of the land at the wind farms, e.g. in the form of a rental agreement for 25, 50 or 100 years between ELECTRA and the municipality. It should be noted that both the present cattle grazing and operation of the quarry at Praia can be maintained. Land for the possible Step 2 Wind Farms should be included in the agreement. The feasibility study does not include any cost of land in the economic and financial analyses.

8.3 Site description, analysis and evaluation of candidate sites

For Cape Verde, the Step 1 Wind Farm project has been implemented and in operation since December 1994. All data and information valid for the Step 1 Wind Farms are therefore available (see e.g. Vol. 2, Sections 3 and 4 as well as contracts for equipment supplies and project progress reports). The site selection for possible Step 2 Wind Farms should be made in the light of this experience from Step 1.

The main advantages of the Step 1 Wind Farm sites are
- favorable, well known and documented wind conditions and wind energy potential
- existing grid interconnections, wind farm monitoring and control systems as well as fiber optic communication from the wind farms to the power stations
- no alternative uses of the land and thus low opportunity costs (price or rent) of land
- little or no present or future obstacles to the wind
- good and known conditions for construction works except for complications due to mountains and wind (complications which have been overcome in Step 1)
- no consequences of noise from the wind farms
- visual impact already accepted by the local community
- no interference to any planned future development of towns or other physical planning
- low human risks to structural damage or failures of wind turbine (large safety distances)

Expansions at the Step 1 Wind Farms are therefore the obvious solutions. Below is a description of other possible sites at Praia, Mindelo and Sal, compared to the sites available for wind farm expansions at the Step 1 Wind Farms.

8.3.1 Praia

The candidate sites at Praia are
a) the plateau of Mt. St. Filipe at the existing Step 1 Wind Farm

b) at the San Francisco road near Mt. St. Filipe and the power cable connecting the Step 1 Wind Farm
c) at the new desalination plant (under construction) and planned power station, Palmarejo

The locations of the Step 1 Wind Farm site and the recommended site for Step 2 are shown in Appendix M, Site maps.

COMPARISON OF CANDIDATE SITES FOR STEP 2 WIND FARMS			
	a) at Step 1 WF	**b) at S. Francisco road**	**c) at desal. plant., Palmarejo**
Land	as for Step 1 WF	among trees, next to military camp, and other land uses seem possible	could possibly be found nearby desalination and power plant
Access	as for Step 1 WF	easier than a)	easy if and when new power station at Palmarejo is in operation
Grid and CMCS	use of existing grid to Step 1 WF, CMCS depends on new power station	possible from existing grid and CMCS as a), but at higher cost than a)	grid connection possible from new grid to desalination plant, but CMCS depends on new power station
Operation	as for Step 1 WF	as a)	easier access than a), but Step 1 and Step 2 as separate wind farms may add complication
Physical planning	as for Step 1 WF	the land is reserved for possible town in the far future, but at low priority	not completely known, but Praia is p.t. being expanded in that direction
Wind energy production	as for Step 1 wind turbines	less than a)	probably less than a), and uncertainty is larger than a)
Environmental impact	easily estimated as up-scaling of the impact of Step 1 WF	new cluster of wind turbines - different visual impact, possibly more noise at nearby houses and less saving of emissions than a)	new cluster of wind turbines - different visual impact, possibly more noise at nearby houses and less saving of emissions than a)
Economy	better than for Step 1 WF due to less investments in roads, grid and crane	higher investment and less energy production than a), i.e. not as good as a)	less energy production (depending on exact siting), and higher investment in CMCS and grid than a)
Sustainability	as for Step 1 WF	similar to a)	better than a) due to the proximity to the planned new power station, but it may also lead to less daily attention to operation of the existing Step 1 Wind Farm
Risks and uncertainties	low due to Step 1 WF, but erosion of road and cable trench at Mt. St. Filipe must be prevented	larger uncertainties than a)	larger uncertainties than a) and b) - uncertainties might be reduced when the planned new power station is in operation

The available distance from Step 1 to the northwestern edge of the plateau of Mt. St. Filipe is approximately 1.4 km. The Step 2 Wind Farm layout could be built as one row as an extension to the northwest of the Step 1 row of wind turbines. There will be practically no array losses. The plateau is large enough to accommodate at least 10 more 300 kW wind turbines.

In conclusion, the feasibility study recommends to build Step 2 on the plateau of Mt. St. Filipe at the existing Step 1 Wind Farm.

8.3.2 Mindelo

The candidate sites at Mindelo are
a) Selada Flamengo, at the eastern slope of Mte. Montona - near the existing Step 1 Wind Farm
b) the valley near the airport road and north of the Step 1 Wind Farm
c) Tope de Bolim near the road connecting Mindelo and Baia das Gatas

Other sites may be available at Mindelo. It may be possible to add 1 extra wind turbine at the Step 1 site.

The locations of the Step 1 Wind Farm site and the recommended site for Step 2 are shown in Appendix M, Site maps.

COMPARISON OF CANDIDATE SITES FOR STEP 2 WIND FARMS			
	a) Flamengo	**b) valley**	**c) Tope de Bolim**
Land	as for Step 1 WF, but new site needs to be developed	among trees	barren land - attempted tree plantation seems unsuccessful
Access	as for Step 1 WF, but new separate access road needed	easier than a)	similar to a)
Grid and CMCS	use of existing grid and CMCS to Step 1 WF with 1.5 km extension	use of existing grid and CMCS to Step 1 WF with 1 km extension	new grid and separate CMCS connection needed
Operation	basically as for Step 1 WF, but wind turbines located in two sites	as a)	Step 1 and Step 2 as separate wind farms may add complication
Physical planning	as for Step 1 WF	as for Step 1 WF, but other land uses seem possible	not completely known
Wind conditions and energy production	as for Step 1 wind turbines	less than a)	probably as a), but uncertainties are larger than a) especially re possible turbulence intensity at the site
Environmental impact	easily estimated as up-scaling of the impact of Step 1 WF	new location of wind farm - different visual impact and less saving of emissions than a)	new location of wind farm - different less predictable visual impact than a)
Economy	better than for Step 1 WF due to less investments in grid, CMCS and crane	less investment and energy production than a), not as good economy as a)	considerably higher investments in CMCS and electric grid than a)
Sustainability	as for Step 1 WF	similar to a)	almost similar to a)
Risks and uncertainties	low due to Step 1 WF experience	similar to a)	larger than a), particularly due to the unknown wind turbulence conditions and the grid and CMCS redesign and expansion needed

The Selada Flamengo is a low ridge on the eastern slopes of Mte. Montona which has a total length of approximately 550 m, enough for up to 7 wind turbines of 300 kW. The terrain is approximately similar to that at the Step 1 Wind Farm, and the wind turbines should be placed on the top of the ridge in one row with a spacing of approximately 3 rotordiameters. There will be no array losses.

It is the opinion of the feasibility study that the Selada Flamengo Step 2 site being only 1-1.5 km from the Step 1 Wind Farm with power line, substation, fiber optic cable connection to the power station and CMCS system facilities as well as expected good wind conditions is very attractive. It is recommended that wind measurements are made as soon as possible by ELECTRA to verify the assumed wind resources.

8.3.3 Sal

The candidate sites at Sal are
a) at the existing Step 1 Wind Farm at Palmeira
b) at Sta. Maria

The locations of the Step 1 Wind Farm site and the recommended site for Step 2 are shown in Appendix M, Site maps.

COMPARISON OF CANDIDATE SITES FOR STEP 2 WIND FARMS		
	a) at Step 1 WF	b) at Sta. Maria
Land	as for Step 1 WF, and land has been handed over free of charge from the municipality	near the sea - other land uses e.g. touristic are likely
Access	as for Step 1 WF, use of existing road	easy, but new road needed
Grid and CMCS	use of existing grid and CMCS to Step 1 WF	connection to existing grid, but new 17km CMCS connection needed - higher cost than a)
Operation	as for Step 1 WF	larger distance from power station to site than a)
Physical planning	as for Step 1 WF	not known - depends on development
Wind energy production	as for Step 1 wind turbines	more than a)
Environmental impact	easily estimated as up-scaling of the impact of Step 1 WF	new cluster of wind turbines - different visual impact, possibly more noise at nearby houses, hotels and touristic sites, but more saving of emissions than a)
Economy	better than for Step 1 WF due to less investments in roads, grid, CMCS and crane	higher investment, higher running costs e.g. for corrosion protection, but more energy production than a)
Sustainability	as for Step 1 WF	similar to a), but maintenance is more critical in particular with respect to corrosion protection due to the proximity to the sea (seen in the wind direction)
Risks and uncertainties	low due to Step 1 WF experience	larger uncertainties than a)

The Step 2 should be as an expansion at Palmeira. The expansion could be either as a) an extra row situated 10 rotordiameters to the northeast of the existing which will cause array losses, or b) if it is one or two wind turbines as an extension of the existing row to the northwest or one on either side of the existing wind turbines in the same line.

8.4 Climate and wind resource assessment

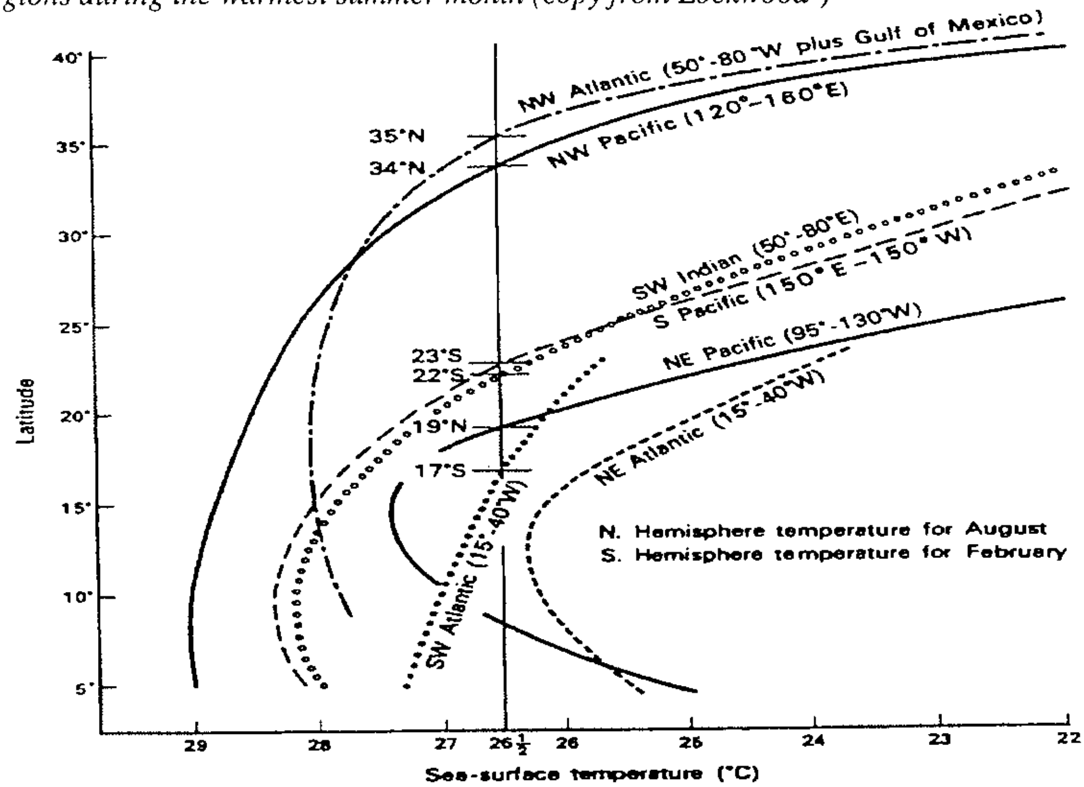
8.4.1 General

The Republic of Cape Verde is an archipelago of located in the Atlantic Ocean 600 km west of the African continent at latitudes 15-17°N and longitudes 23-25°W. The climate of Cape Verde, being on the equatorial side of the subtropical high-pressure systems at 30°N and north of the equatorial trough with a relative low-pressure, is a trade wind climate for most of the year except for short periods between July and October. Descriptions of the regional climatology in the trade winds and the tropical climates can be found in the literature about world climatology as e.g. in *Lockwood*[1].

The trade winds are known for their extreme constancy in speed and direction - more so than in any other climate zone - which is also what is found in the wind data recorded at Sal International Airport and by previous wind energy projects in Cape Verde. Furthermore, the trade-wind inversion is a feature of the climate zone, which greatly influences the climate of Cape Verde. This is particularly important when extrapolating meteorological data measured at one location and height to another site and height in mountainous terrain. The height of the base of the inversion, through which the lower layers of air are not mixing with upper layers, is generally less than 2 km and at Cape Verde (at least above the sea) reported[1] to be of the order of 500 - 750 m. It should be noted that the base of the trade-wind inversion is not at the top of the trade-wind flow, but rather in the middle of the current. The total depth of the flow may thus be considered at least 1 - 1.5 km, but less than 4 km. However, for the purpose of flow modeling of speed-up over hills in Cape Verde in connection with the feasibility study, we will use an average depth/height of the layer influencing the speed-up mechanisms at the ground of 1 km.

During July-October from time to time the climate changes from trade winds to other types of weather due to the intertropical convergence zones more northerly position. These other weather situations bring changing wind directions other than the NE or ENE and less steady

Figure 8.1 Latitude variations of sea-surface temperatures in the various storm development regions during the warmest summer month (copy from Lockwood[1])



[1] John G. Lockwood "World Climatology, An environmental approach", Edward Arnold Publishers Ltd, 1974.

winds - even periods with calms - as well as occasional heavy rains. The rainfall, however, is totally low and only a few days a year. Cape Verde is one of the so-called Sahel countries, signifying an extremely dry climate. Though the islands e.g. at Praia gets typically 300 - 600 mm of rainfall annually, the evaporation is high and the terrain and its geology is such that only a part of the rainfall remains as ground water.

To be able to predict the extreme maximum wind speeds that may occur within a certain period in the future is of importance for design of the wind turbine structure. According to meteorological data available, Cape Verde does not experience extremely high maximum wind speeds, although the average wind speeds are high. This matches well information from the literature[1]

a) that trade winds are extremely steady with very constant wind speeds
b) that the northeast part of the Atlantic Ocean in latitudes 5° - 25°N and longitudes 15° - 40°W is outside any zone of tropical storms/cyclones/hurricanes due to the sea-surface temperatures being below 26.5°C as shown in Figure 8.1.

General statistics of temperature and humidity recorded at Sal Airport and Praia at near sea level elevation, but valid at Mindelo as well, are as follows:

Annual average temperature	24°C
Range of monthly average temperatures	21 - 27°C
Estimated total range of temperatures	10 - 40°C
Annual average humidity	73 % relative
Range of monthly average humidity	69 - 75 % relative
Estimated total range of humidity	40 - 100 % relative

The climate in Cape Verde is relatively corrosive near the ocean due to the contents of salt in the air and the high annual average temperature. The corrosion gets less severe when moving inland some kilometers in the direction of the wind and further when moving to sites on hills and mountains, since the amount of salt in the air carried to such places will be less than at the coast at sea level. The corrosion problem can be handled by proper design of equipment and maintenance as can be seen from at the Step 1 Wind Farms and the Ponta d'Agua wind turbines installed in 1985.

Of special relevance for design of machinery for operation in Cape Verde, it should be mentioned that in addition to the dust blown up from the dry soil locally, very fine dust can be carried by the trade winds all the way from the Sahara to Cape Verde, where it is called the "bruma seca" (dry fog). The bruma seca occurs every winter for a period of some weeks in December, January or February.

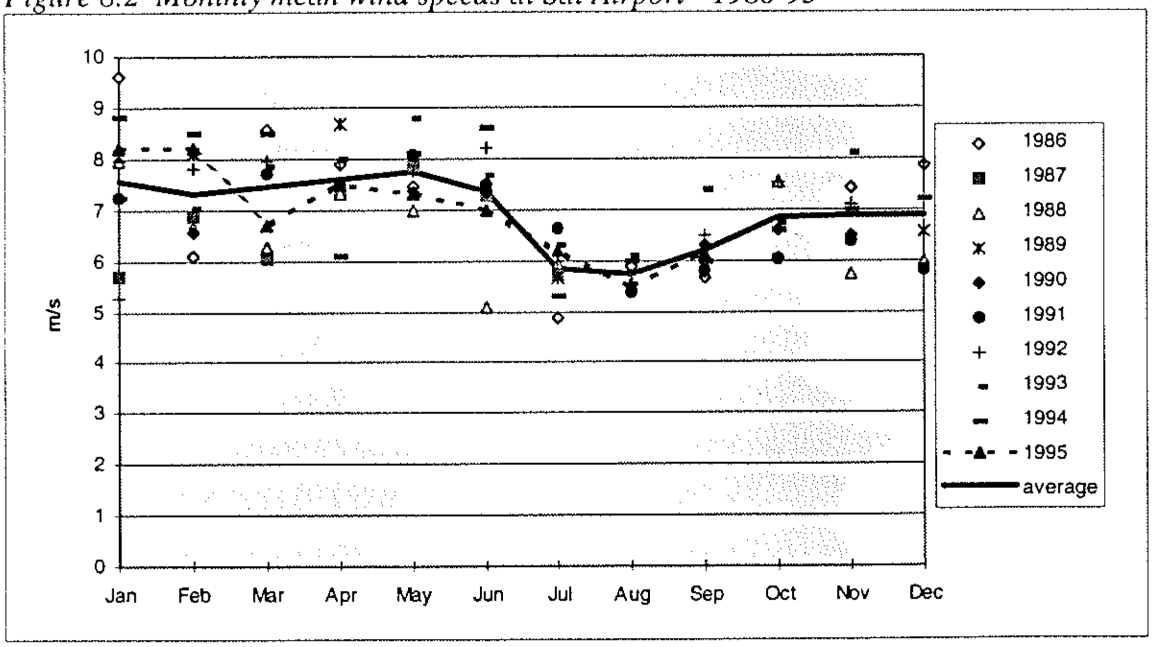
8.4.2 Wind energy resources

The wind energy resources of Cape Verde have been estimated by several previous studies analyzing data available at that time, e.g. the Wind Energy Assessment Study, UNSO, 1986, and the Wind Farm Project Feasibility Study, DANIDA, 1990. In all cases it has been concluded that the general potential expressed in terms of the annual average wind speed 10 m above ground level at sea level elevation in flat open homogeneous terrain with a surface roughness, z_0 , of 0.01 m is approximately 7 m/s. The corresponding probability density distribution and the seasonal variation found using the Sal Airport meteorological data are shown in Table 8.1 and Figure 8.2.

Table 8.1 Wind speed distribution at Sal Airport - direction sector by direction sector and total - frequency of occurrence in direction sectors and frequency of occurrence in wind speed bins

STATISTICS OF SAL AIRPORT WIND SPEED AND DIRECTION MEASUREMENTS - 1986,87,94,95															
Sect. (deg)	Freq. (%)	Frequency (per mille) for the given wind speed bins (m/s) 0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-11	11-13	13-15	>15	Weibull A(m/s)	k
0:	13.8	3	9	39	77	138	179	183	153	110	95	13	1	0	7.1	3.23
45:	65.2	1	2	17	41	80	143	182	182	142	171	37	2	0	8.0	3.52
90:	18.9	2	2	24	48	77	126	163	164	146	195	50	2	0	8.2	3.52
135:	0.6	69	17	176	176	204	132	105	66	17	39	0	0	0	5.0	2.23
180:	0.2	203	0	81	81	98	146	211	114	33	33	0	0	0	5.7	2.81
225:	0.1	352	0	113	141	197	169	28	0	0	0	0	0	0	3.7	2.17
270:	0.2	248	40	317	218	99	79	0	0	0	0	0	0	0	3.1	2.27
315:	1.0	40	22	60	171	209	206	149	38	44	48	13	0	0	5.8	2.42
Total		3	3	24	50	90	145	178	172	136	162	36	2	0	7.8	3.42
Mean wind speed: 7.0 m/s															
Mean energy density: 274 W/m²															

Figure 8.2 Monthly mean wind speeds at Sal Airport - 1986-95



Estimation of the wind energy production potential at a given site in Cape Verde - as everywhere in the world - should in principle be done using the Wind Atlas method[2] or similar. This implies extrapolation of nearby representative wind statistics from a high quality wind measurement station taken at a topographically simple site for a climatologically long enough period to the potentially interesting wind farm site.

The best quality long term statistics of wind data and at the same time the topographically simplest site is at Sal Airport, so the Wind Atlas method should in principle be applied for the Sal Airport data, as it was done in the previous feasibility study for the Step 1 Wind Farms. However, in the case of the Step 2 Wind Farms, the available information from the Step 1 Wind Farms provide a very good basis for estimating the wind energy production directly on the basis of the wind energy production statistics of 1995. It has been proven in *Delgado et al*[3] that using the production statistics to calculate production estimates, the uncertainties of predictions are less than 10 %, when excluding year to year climatological variations.

As seen from Figure 8.2, year to year variations may be considerable with annual averages recorded in the 10-years period from 6.4 to 7.4 m/s according to the Sal Airport statistics. The climatological average of 7.0 m/s, however, seems to be confirmed by the latest 10-years record shown. It is furthermore seen that 1995 approximately will be an "average wind-year", and that the wind energy production recorded in 1995 at the Step 1 Wind Farms may be considered good estimates of the long-term average of expected annual wind energy production from wind farms at those sites in Cape Verde.

Unfortunately, errors in the calibrations of the wind direction measurements have occurred at the Step 1 Wind Farms in the first months of 1995, so reliable wind statistics as a function of the wind direction do not exist from these wind measurements. Such information should have been used for extrapolating the data by means of the Wind Atlas method and when calculating wind farm array efficiency.

Fortunately,
a) there are no wake effects in play in the wind farms since the wind farm layouts are in one row of wind turbines perpendicular to the trade wind direction, and
b) extrapolation is not needed in Praia and Sal.

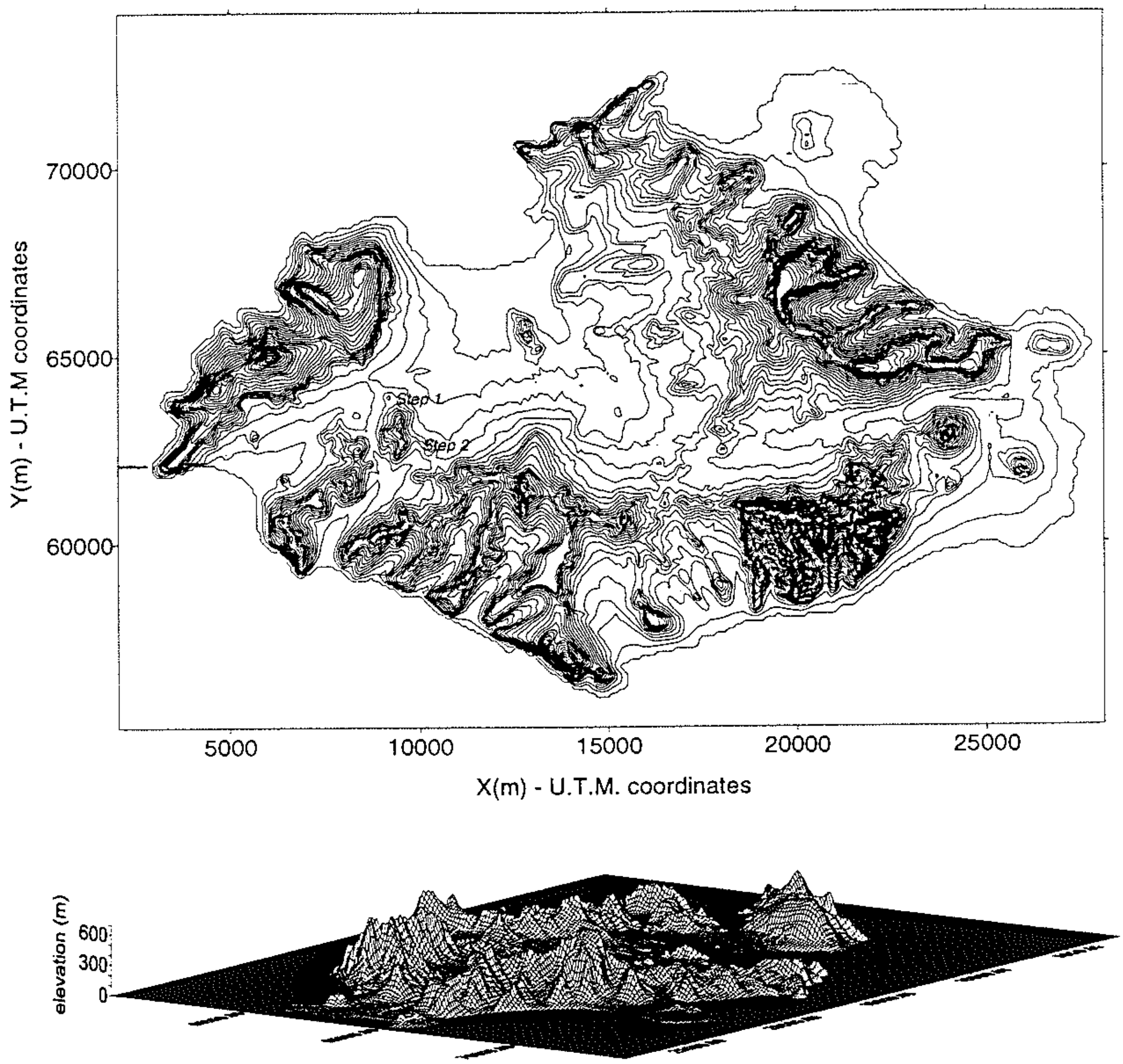
In Mindelo, however, the Step 2 Wind Farm site is not exactly identical to the Step 1 site, but rather at the Selada Flamengo. At Mindelo, a comparison of the wind energy potentials at Mte. Montona and Selada Flamengo thus has to be made using the Wind Atlas method, i.e. the WA^{s}P[4] program, with Sal Airport data as input. Figure 8.3 and Figure 8.5 show the digitization of the S. Vicente topography and an aerial view generated by the computer of the Step 1 and Step 2 sites with an indication of the location of wind turbines.

The result of the wind atlas analysis at Mte. Montona and Selada Flamengo is shown in Figure 8.4. The expected annual average wind speed at 30 m above ground level is shown in color codes on top of the height contour lines of the sites 1 and 2. The color codes are

[2] "European Wind Atlas", Risø National Laboratory, 1989, ISBN 87-550-1482-8
[3] Delgado, Hansen, Tande and Nørgård "Running-in and economic re-assessment of 15% wind energy penetration in Cape Verde", EWEA special topic conference, Helsinki, 5-7 September 1995
[4] "Wind Atlas Analysis and Application Program (WA^{s}P)", Risø National Laboratory, 1993

normalized values of wind speeds, where the common normalization is done on an (in this connection) arbitrarily chosen value, which enables comparison between the sites.

Figure 8.3 Topography of S. Vicente as digitized for the Wind Atlas analysis



In addition to the WA^{s}P-modeling, comparison of wind conditions at site 1 and 2 could be made by means of wind measurements at the two sites. Such wind measurements were initiated April 1996. An NRG wind measurement station was installed at site 2 (Selada Flamengo), measuring wind speeds as 5 minutes average values in two levels - 20 m and 30 m above ground level (agl) for comparison with the wind measurements now being made by the Central Monitoring and Control System (CMCS) of the Step 1 Wind Farm which is in operation at Mte. Montona. The CMCS data are 10 minutes average values in 10 m and 30 m agl. Comparisons for the first 10 days of measurements are shown as plots of the daily average wind speeds and of the average diurnal variation of the wind speed in 30 m agl at the two sites. These comparisons are shown in Figure 8.6 and Figure 8.7.

Figure 8.4 Annual average wind speeds in 30 m agl at Mte. Montona and Selada Flamengo (contour lines of topography shown) - normalized values for comparison of Step 1 site and Step 2 site, ***modeled using the*** $WA^{s}P$ ***program*** *with Sal Airport wind data as input*

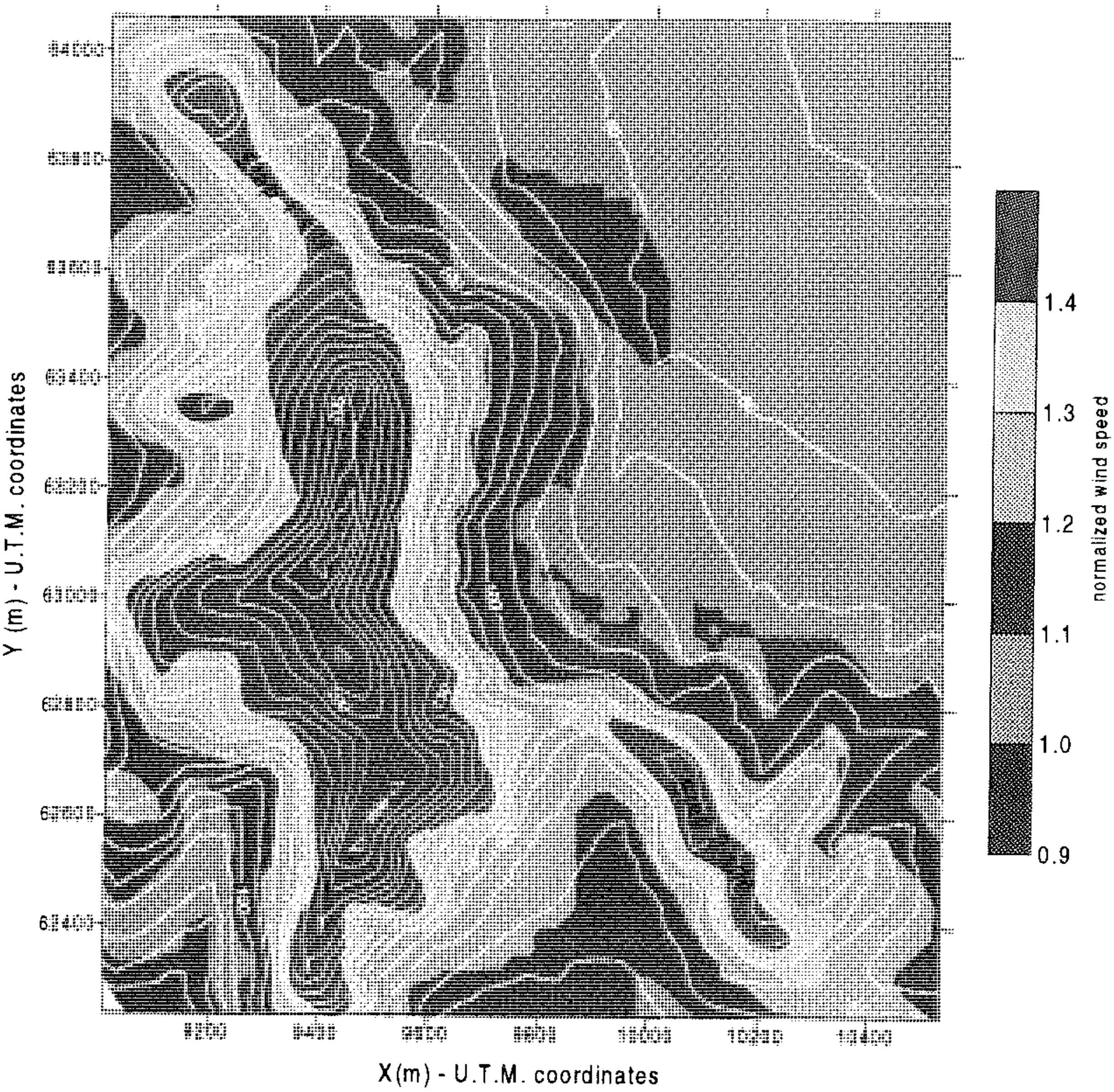


Figure 8.5 Computer generated aerial view of the wind farm sites - Mte. Montona and Selada Flamengo - at Mindelo

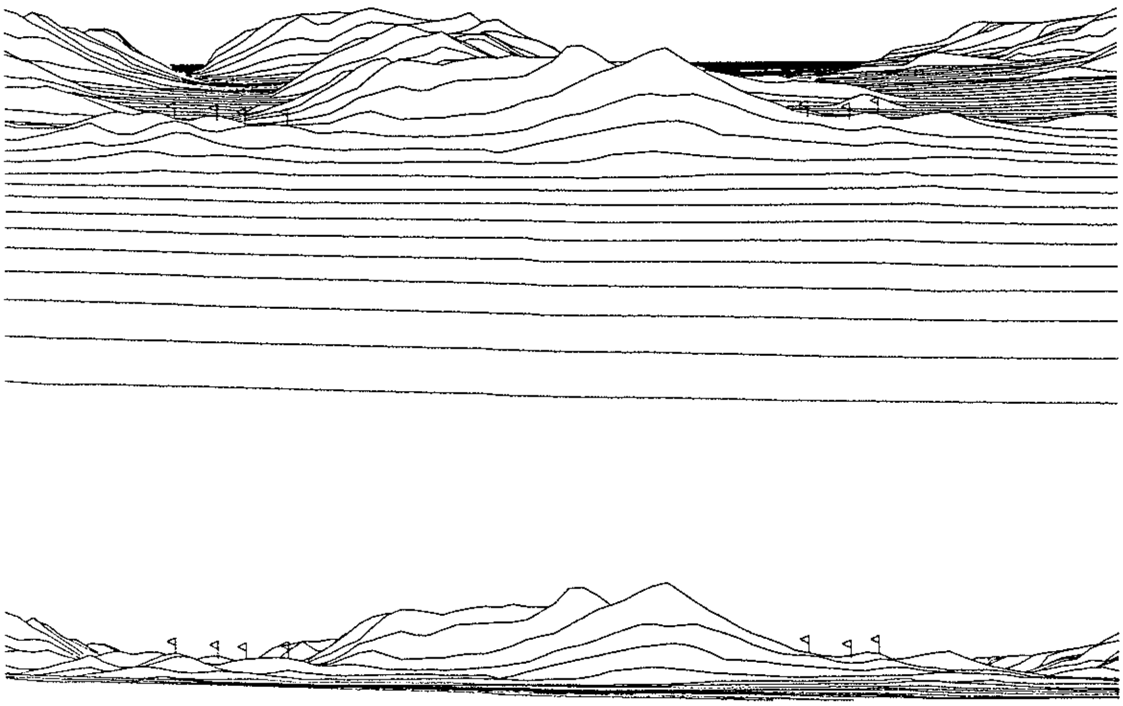


Figure 8.6 Comparison of wind speeds measured at Mte. Montona (site 1) and Selada Flamengo (site 2) - daily average values in the first 10 days of the measurement period

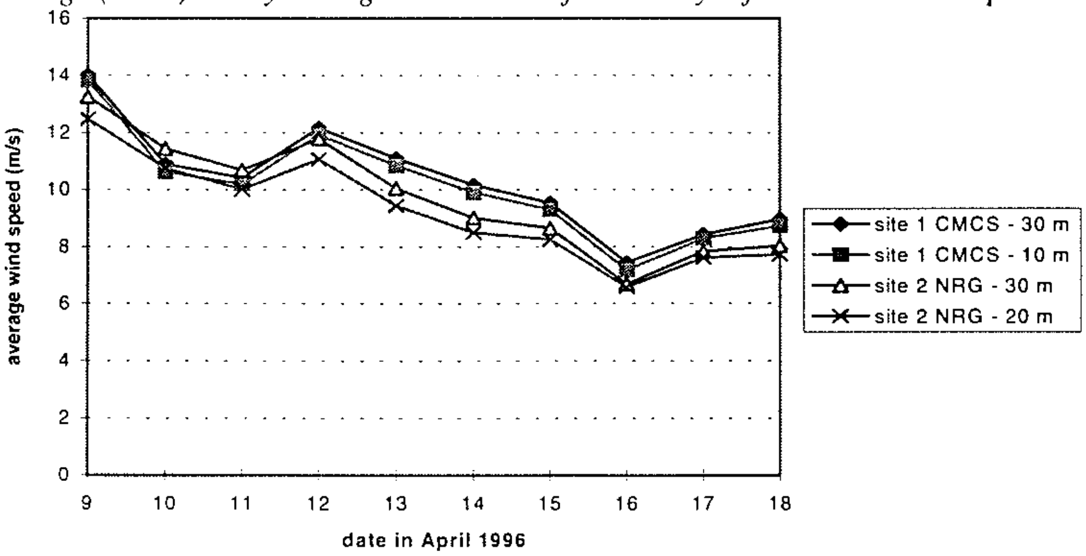
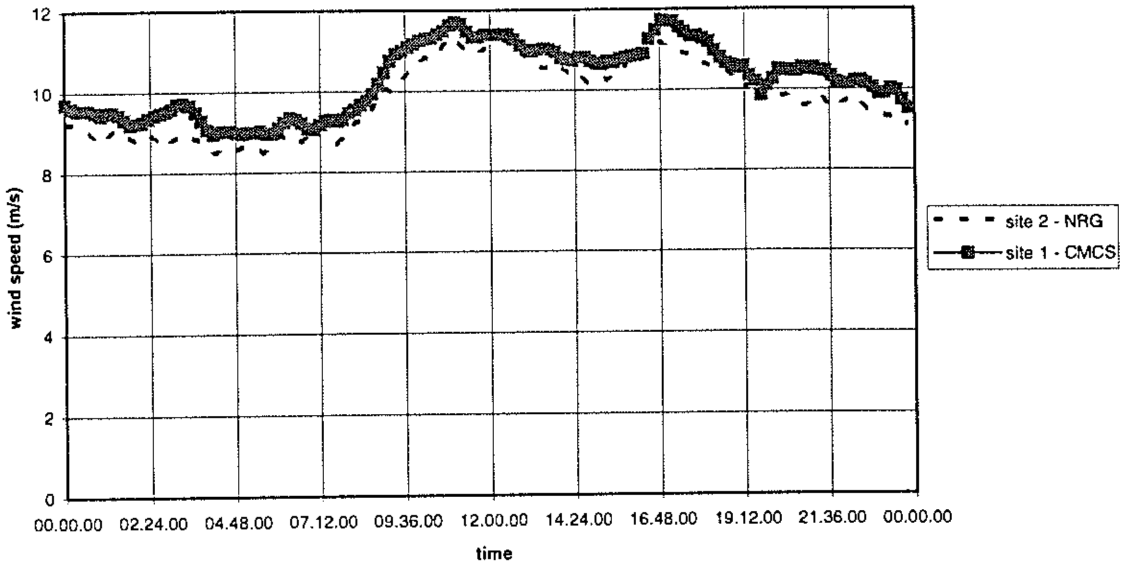


Figure 8.7 Comparison of wind speeds measured at Mte. Montona (site 1) and Selada Flamengo (site 2) - average diurnal variation during 9-18 April 1996 (30 m agl)



It is seen from Figure 8.6 and Figure 8.7 that wind speeds measured in the analyzed measurement period (9-18 April 1996) at the NRG-station in site 2 typically are some 5-10 % lower than at the CMCS-station in site 1. This difference is seen to match well with the prediction by the WA^{s}P-modeling for the location of the NRG-station as indicated in Figure 8.4. The WA^{s}P-modeling furthermore shows that slightly higher wind speeds may be found on the ridge itself of the Selada Flamengo (site 2) than on the little more northeasterly location chosen for the NRG-station. The measurements of the NRG-station does, however, combined with the WA^{s}P-modeling serve as a quite reliable documentation of the wind energy production estimation assumed.

From Figure 8.4, Figure 8.6 and Figure 8.7, it is concluded that wind speeds at Mte. Montona and Selada Flamengo on an average may be assumed to be similar, although wind speeds at Selada Flamengo may vary somewhat across the site. It is furthermore recommended

- to continue the NRG-station measurements at Selada Flamengo and repeat the comparison with the CMCS data from the Step 1 Wind Farm for a longer measurement period than 10 days - preferably a complete year,
- to do the micro-siting of the Step 2 Wind Farm at Selada Flamengo taking the results of the WA^{s}P-modeling into consideration - i.e. siting the wind turbines along the ridge where the highest wind energy resources are available, but still with one and the same distance between any two neighboring wind turbines.

The uncertainty at Mindelo associated with the extrapolation from the Step 1 Wind Farm at Mte. Montona to the Selada Flamengo site has to be added to the general uncertainty assumed, which seems to be low - less than 10 % according to the model validation made (see e.g. Appendix N). With the experience from the Step 1 Wind Farm, the WA^{s}P-modeling and the comparison of wind measurements reported above, the uncertainty of extrapolation from the Step 1 Wind Farm at Mte. Montona to the Selada Flamengo site seems low - lower than most such estimates in wind farm feasibility studies around the world. Further documentation will be provided by the continued wind measurements.

In conclusion, it is the recommendation of the feasibility study to use the actual wind data measured in 1995 at the Step 1 Wind Farms to generate the wind speed probability density distributions for wind energy production estimation for the Step 2 Wind Farms at the selected wind farm sites. Table 8.2 gives the resulting values of estimated annual average wind energy resources at 30 m height above ground level (agl) in terms of the annual average wind speeds U_{mean} and the Weibull probability density distribution scale and shape parameters (A, k).

Table 8.2 Estimated wind energy resources at a height of 30 m agl - annual average wind speed (U_{mean} *)and Weibull scale and shape parameters* (A, k)

	U_{mean} (m/s)	Weibull - A (m/s)	Weibull - k
Praia - Mt. S. Filipe	7.8	8.9	3.62
Mindelo - Selada Flamengo	10.4	11.7	4.02
Sal - Palmeira	7.4	8.3	3.62

As input to the power system modeling, seasonal and diurnal variations of wind speeds have been determined. The main results are shown in Table 8.3 and Figures 8.8, 8.9 and 8.10.

Table 8.3 Seasonal variation of wind speeds at 30 m height above ground level given as quarterly average values of U_{mean} *in m/s*

	1. quarter	2. quarter	3. quarter	4. quarter
Praia - Mt. S. Filipe	8.9	8.3	6.1	7.8
Mindelo - Selada Flamengo	11.6	11.6	8.6	9.3
Sal - Palmeira	8. 3	7.3	5.9	7.5

Figure 8.8 Diurnal variations of wind speeds at Mindelo at 30 m agl for the four quarters of the year

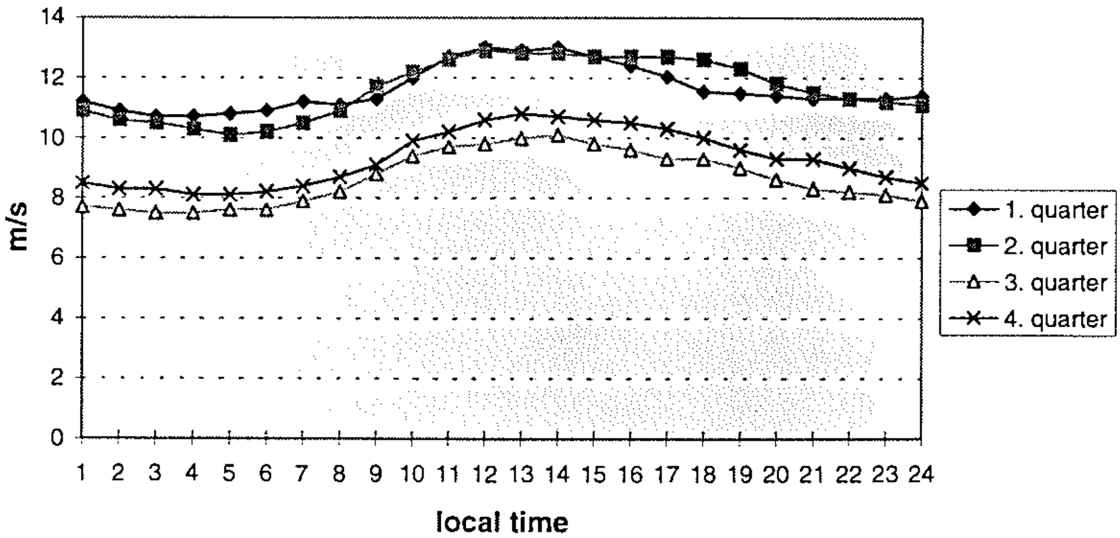


Figure 8.9 Diurnal variations of wind speeds at Praia at 30 m agl for the four quarters of the year

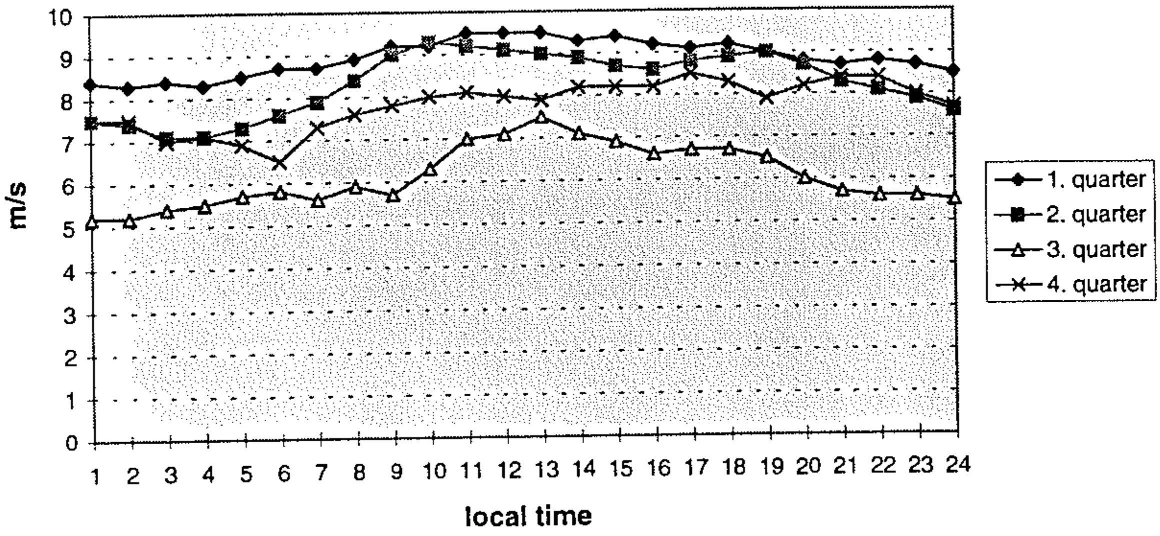
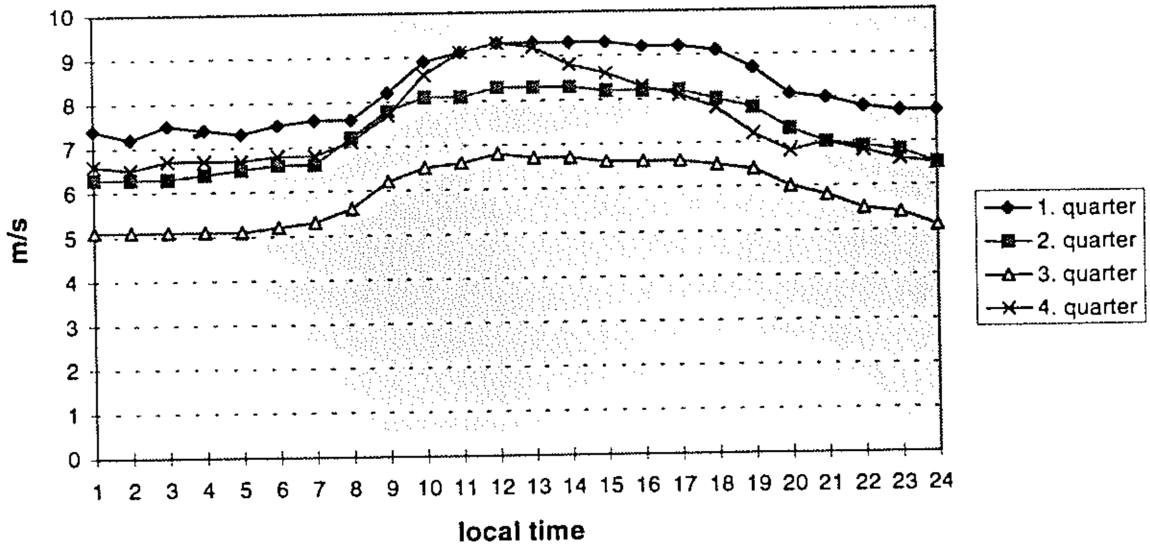


Figure 8.10 Diurnal variations of wind speeds at Sal at 30 m agl for the four quarters of the year



8.5 Wind turbine type and design

General

The type and size of the wind turbines of the Step 1 Wind Farms has proven appropriate with respect to transportation, erection and operation.

The wind turbines for Step 2 wind farms should be based on and of similar quality as an approved type in accordance with the Danish regulations and requirements, i.e. class A or B

Danish Type Approval for operation in the local climatic conditions at the wind farm sites in Cape Verde and for operation in the local power systems at which they are to be installed.

Similar type approval systems to the Danish today only exist in Germany and Holland. An international standard or type approval system replacing the three existing national systems does not exist yet. Projects in other countries than Denmark, Holland or Germany often require a type approval from one of the three countries. Other manufacturers than Danish can obtain a type approval according to the Danish Type Approval System.

Safety requirements

The wind turbines should be designed in accordance with the requirements of IEC 1400-1; International Standard for Wind turbine generator systems - Part 1: Safety requirements; first edition 1994 (or any later version).

The Wind turbine class should be: I or S.

Based on the available data it is estimated, the basic design wind parameters (V_{ref}, V_{ave}, I_{ave}) at the proposed Step 2 Wind Farm sites in a height above ground level of 30 m should be assumed to be as specified in Table 8.4.

Table 8.4 Design wind parameters

		Praia	Mindelo	Sal
V_{ref}	$\leq$	37.5 m/s	37.5 m/s	37.5 m/s
V_{ave}	=	7.8 m/s	10.4 m/s	7.4 m/s
I_{ave}	$\leq$	0.17	0.17	0.17

The above values have been estimated based on recordings of the wind at the Step 1 Wind Farms and assumes upstream conditions (to the northeast of the wind farm sites) to be undisturbed by other wind turbines, buildings or obstacles. The estimates are based on only 1 year of data from the Step 1 Wind Farm sites and 4 years of data from Sal airport.

Due to the limited amount of data for the extreme wind analysis, it is recommended that the above specification of wind conditions at the sites should be updated based on available data at the time of signing of any contract for supply of wind turbines for Step 2 Wind Farms.

It should be noted, however, that proper extreme value analysis using a statistical approach as e.g. described by Lawson[5], indicates that the extreme 10 minutes average wind speed with a recurrence period of 50 years at 30 m agl, V_{ref}, is less than 30 m/s in all three wind farm sites, and not the 37.5 m/s recommended in Table 8.4. This matches well expectations of extreme wind speeds estimated based on the "mother" wind speed distributions with Weibull shape parameters higher than 3.5. All measured wind speed probability density distributions at Cape Verde are very narrow, indicating very steady winds, and low probabilities of occurrence of high wind speeds, which is in agreement with the climatology as described above.

[5] T.V. Lawson "Wind effects on buildings, Statistics and Meteorology", Applied Science Publishers Ltd, 1980.

All in all it seems that extreme wind speeds at the selected Step 2 Wind Farm sites in Cape Verde are considerably lower than extreme wind speeds for which wind turbines are designed in e.g. Denmark, California, Germany or the UK. The relatively large uncertainty with which the V_{ref} is given is therefore not considered a major risk of failure.

Experience from Step 1

Based on the experience from Step 1, relative to requirements of the Step 1 contracts, more emphasis should be given to

- planning which takes into account the time consuming transportation of the large crane
- planning should aim at works being carried out at the Mindelo site in the less windy period (July, August, September)
- pitch-angle adjustment of wind turbine blades
- temperature requirements and set-points of temperature sensors in particular in generators
- testing and documentation of CMCS software prior to installation
- dust-proof cabinets and additional cooling of hardware for monitoring and control systems
- procedures and equipment for cleaning of blades and machinery
- special hoisting and handling equipment for moving spare parts to and from the nacelle during maintenance and repair should be considered.

O & M

Special maintenance which requires a large crane may be costly and time consuming, since the only large crane available in Cape Verde is the one supplied with the Step 1 Wind Farms and the fact that this large crane may have to be moved from one island to another.

The lifetime of the wind turbines as well as the maintenance effort and costs necessary cannot yet be precisely determined. However, the experience until now indicates that normal estimates and procedures from other wind farms with similar wind conditions will apply.

8.6 Performance verification of wind turbines in Step 2 Wind Farms

It is recommended that the quality assurance of the wind turbines in the Step 2 Wind Farms includes performance verification of the wind turbines installed. The performance verification should preferably be done in accordance with the draft IEC International Standard for Wind turbine generator systems - Part 12: Power performance measurement techniques - WG6 24/1-1995 (or any later version if available).

The location of meteorological measurements masts should be chosen and documented according to the requirements to a test site (clauses 2 and 6), which may mean that it will be possible to carry out power curve measurements at the Palmeira site at Sal only.

Using the estimated total Weibull wind speed distribution (A, k), the annual energy production (AEP) can be calculated for each power curve. The average values of AEP is determined and compared to the contractually guaranteed value at standard climatic conditions.

The AEP_W requested from each Tenderer shall be calculated based on the documented power curve multiplied by a reduction factor (K_{AEP}), which is the Tenderers safety margin due to manufacturing and measurement uncertainties, etc. The documented power curve shall be given in accordance with the type approval for the wind turbine. Both the documented power curve, AEP_W and K_{AEP} shall be given in the Tenders.

In case AEP is smaller than AEP_W, the lost energy production in the entire wind farm shall be compensated by modifying all wind turbines, or installing extra wind power capacity, or by payment of penalties corresponding to the lost energy calculated as ($AEP - AEP_W$) $\times$ number of WTGS of that type.

The Tenderers shall specify a guaranteed wind turbine availability which shall be valid for all his wind turbines and monitored by the wind turbines local control system and a central monitoring and control system.

Wind conditions at the site to be used for production estimates, AEP_W

The wind speed distributions to be used for production estimates are assumed to be Weibull distributed. The Weibull scale (A) and shape (k) parameters for a height of 30 m above ground level (agl) are given in Table 8.5 below.

Table 8.5 Weibull parameters - A, k - of the wind speed distribution to be used for energy production estimation

	Weibull - A	**Weibull - k**
Praia - Mt. St. Filipe	9.0 m/s	3.62
Mindelo - Selada Flamengo	11.7 m/s	4.02
Sal - Palmeira	8.4 m/s	3.62

In Selada Flamengo - Mindelo, wind speeds should be assumed to be constant with height from 30 to 40 m agl. In Mt. St. Filipe and Palmeira, extrapolation to heights different from 30 m above ground level can be done using a logarithmic profile with $z_o = 0.05$ m.

Measurement equipment and accuracy

Measurement procedures, sampling frequency, equipment quality and accuracy as well as analyses methodology shall be in accordance with the draft IEC International Standard for Wind turbine generator systems - Part 12: Power performance measurement techniques - WG6 24/1-1995 (or any later version).

9. Wind power integration concept

9.1 Design considerations

Alternative concepts for the Step 2 wind farms have been discussed throughout the feasibility study between the project parties. A simple concept has been agreed upon basically considering the Step 2 to be an extension of the Step 1 wind farms without adding any advanced control systems.

Erecting the Step 2 wind turbines at the same sites as the Step 1 minimizes the cost of the Step 2 as the fiberoptic cable, the wind farm monitoring and control system and the electric grid connection of the Step 1 can be utilized also for the Step 2.

Re. the design and choice of wind turbines and wind farm monitoring and control system, some modifications for a Step 2 will be considered. These are briefly:

- The wind turbines may not necessarily have to be Nordtank 300 kW, but could be any size that could be erected by the use of the available crane procured by Step 1. Wind turbines should be procured through competitive bidding and basically evaluated on quality and guaranteed life-cycle price per unit of energy produced.
- The wind turbines immediate (1 Hz) peak output power must be limited.
- The wind turbines in a farm should not be allowed to start at the same time.
- Monitoring of wind power and wind speed 10 minutes standard deviation should be included.
- Indication of the minimum and maximum wind power production envelope for the next 10 minutes.
- Optional automatic stop of the wind turbines in case the production exceeds a certain set maximum allowable level. The level should be decided on-line by the (diesel) power plant operators from the remote wind farm controller (PC) at the diesel power plant control room or optionally follow a preprogrammed curve related to the daily load pattern. After an automatic stop, the controller should release the turbine for operation after a certain time delay (10 minutes) as soon as the total production is estimated to no longer exceed the maximum allowable level.
- Optional connection of dump-load for dissipation of 1 Hz peak output power from one of the wind turbines.
- Indication of some (5 to 10) minutes forecast of wind power production. This will require installation of a wind measurement mast some 10 km upstream of the wind farms.
- Monitoring of each diesel generator production (10 min. avg. + std) and suggestion for start and stop.

The Step 2 shall as the Step 1 turbines be possible to operate also in case the wind farm monitoring and control system fails.

9.2 Power system operation with wind power

A power system should basically be operated so that

- electricity is supplied according to given voltage quality standards and with a high reliability, and
- power system operation cost is minimized.

In practical terms the objectives above may be met by operating the minimum amount of diesel capacity still sufficient to supply the electricity according to standards. A high reliability to meet the demand at all situations is maintained by requiring a margin between the load and the spinning capacity.

A basic criteria for stable operation is that the power balance is maintained:

$$P_{dg} + P_w = P_l \qquad (1)$$

Here is P_{dg} (kW) the diesel power plant output power, P_w (kW) the wind power output and P_l (kW) the total consumers load including line losses.

As the consumer loads and wind power output may vary, the diesel power plant must be able to absorb these power variations. The sufficient spinning capacity at the diesel power plant may be determined by the power plant operators as:

$$P_{sp} \cdot (1 - k_{lm}) \geq P_l - P_w \cdot (1 - P_{wrat} \cdot k_{wm} / P_w) \qquad (2)$$

for $P_w \geq P_{wrat} \cdot k_{wm}$ else

$$P_{sp} \cdot (1 - k_{lm}) \geq P_l \qquad (3)$$

Here P_{sp} is the spinning diesel capacity, k_{lm} is the load margin factor, P_{wrat} is the rated wind power output and k_{wm} is the wind margin factor. The wind margin factor may be estimated as:

$$k_{wm} = (1 - k_{wcap}) P_{wavg} / P_{wrat} \qquad (4)$$

where k_{wcap} is the wind power firm capacity factor and P_{wavg} is the annual average wind power output. The wind power firm capacity factor may be determined from loss of load expectation calculations, see section 11.

Assuming that the spinning diesel capacity is determined by equation (2) and (3), the maximum permitted momentary wind power output must be limited as to respect the power regulation and the technical minimum load of the diesel power plant as expressed by the two below equations:

$$P_{sp} \cdot k_{reg} \geq \Delta P_l + \Delta P_w \qquad (5)$$

$$P_{sp} \cdot k_{tech} \leq P_l - P_w \qquad (6)$$

Here, k_{reg} is the diesel plant power regulation factor, ΔP_l and ΔP_w is expected fast load and wind power variations, and k_{tech}. is the technical minimum load of the diesel generators. Neglecting load variations, and expressing ΔP_w as

$$\Delta P_w = P_w \cdot (1 - k_{wcap}) \qquad (7)$$

equation (6) may be rewritten as

$$P_{sp} \cdot k_{reg} \geq P_w \cdot (1 - k_{wcap}) \qquad (8)$$

Equation (6) and (8) is utilized as to calculate the maximum allowed momentary / immediate wind power output as a function of the load and spinning capacity for Praia, Mindelo and Sal in the three figures below. The graphs are drawn assuming k_{reg} = 40 % of the spinning diesel capacity, k_{tech} = 25 % of the spinning diesel capacity, and k_{wcap} = 20 % of the installed wind power capacity. It should be noted that the firm wind power factor in section 11 is shown to be higher than 20 %.

Figure 9.1 Maximum permitted immediate wind power output as a function of load and spinning capacity.

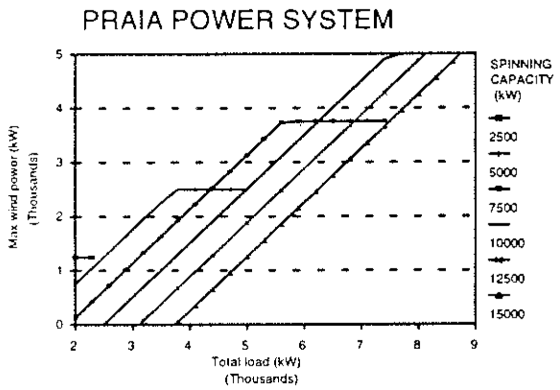


Figure 9.2 Maximum permitted immediate wind power output as a function of load and spinning capacity.

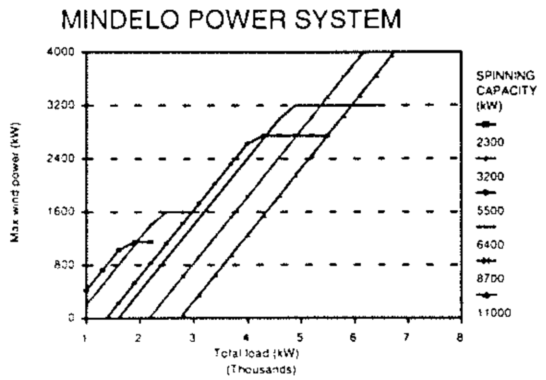
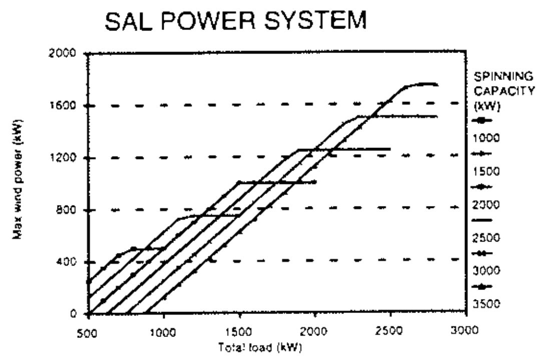


Figure 9.3 Maximum permitted immediate wind power output as a function of load and spinning capacity.



10. Electrical grid design

10.1 Scope of analysis

With the purpose of investigating the steady state impact on the ELECTRA power systems of Sal, Mindelo and Praia when introducing the wind turbines of the Step 1 wind farms and the additional wind turbines of the possible Step 2 extensions of the wind farms, Load Flow analysis has been performed. The specific objectives of the Load Flow analysis is recommendations on possible grid reinforcements and wind farm grid connections, possible allocation and sizing of capacitor banks, possible constraints on the operational strategy of each grid and finally to check each grid for possible steady state voltage problems in selected worst cases.

It should be noted that the full impact on the three ELECTRA power systems of expanding each wind farm with a number of wind turbines in a possible Step 2, can not be safely revealed *only* by steady state Load Flow analysis as included in this feasibility study. To gain the necessary and full insight on these island power system capabilities in absorbing a high wind penetration, a dynamic and transient stability analysis has to be accomplished. Possible problems in the dynamic quality of voltage and frequency under worst case wind and load conditions are yet to be detected. Possible low frequency power swing modes or power oscillations between energized rotating electrical machines are yet to be detected in order to prepare counter actions to prevent unforeseen blackouts. Possible damage of equipment caused by unforeseen transient overvoltages have to be analyzed and protective measures taken.

10.2 Findings and recommendations

In the three ELECTRA grids no critical high or low voltages have been detected in any of the selected worst cases analyzed.

The voltage rise across the (long) wind farm grid connection cables is fully acceptable in all cases on all three islands.

The power losses in the wind farm grid connection cables is fully acceptable in all cases on all three islands.

No capacitor banks should be installed only with the purpose of compensating the full-load reactive power demand of the wind turbine generators. This is provided by the production of capacitive reactive power by the wind farm grid connection underground cables themselves in all cases in each of the Sal, Mindelo and Praia grids.

Due to the rapid growth of the electrical grid in Praia and Mindelo, and due to the planned new power station in Praia, capacitor banks have been included in the Load Flow analysis on these grids. In Praia the capacitor bank (-1600 kVAr) is assumed connected to the old power station high voltage busbar (15 kV) providing voltage support in high load situations as the total power production is assumed supplied solely from the new power station and the wind farm. In Mindelo the capacitor bank (-2000 kVAr) is likewise assumed connected to the power station high voltage busbar (6.3 kV) providing voltage support in high load situations mainly as the grid is assumed operated at its present voltage level of 6.3 kV. When upgrading to a system voltage of 20 kV, as planned in the future, the present low voltage problems will most likely be eliminated. On these grounds the high voltage capacitor banks are not included in the final project budget for electrical grid equipment.

The grid power factor is maintained or even improved in each grid when introducing the wind turbines and grid connections of the Step 1 wind farms and the possible extensions of Step 2.

It can generally be concluded, that none of the Sal, Mindelo and Praia grids, in the assumed state of 1998, has shown problems in absorbing neither the wind turbines and grid connections of the Step 1 wind farms nor the possible Step 2 wind farm extensions in terms of steady state power flow.

It is recommended, that an electrical grid study concerning the necessity of installing capacitor banks in Praia and Mindelo should be conducted. Especially in the Praia grid when introducing the planned new power station. This study should comprise sizing and location of the capacitor banks as well as operational strategies for controlling each capacitor bank level of compensation.

Finally it is independently concluded by ELECTRA, RISØ and ELSAMPROJEKT A/S, that a full dynamic and transient stability analysis must be conducted as a necessity prior to *any* expansion of the Step 1 wind farms.

10.3 Methodology

The electrical layout of the proposed wind farms and the wind farm grid connections are preliminary designed using experience from previous modern wind farms in combination with extensive Load Flow analysis on the total power systems in question.

The Load Flow analysis is based on computerized grid equivalents of the three ELECTRA grids. These computer grid equivalents are established by collecting all relevant data on the existing grids on all grid components such as lines, cables, transformers and generators including the total knowledge of the grid layout themselves extended with all planned and approved grid extensions. The wind farm preliminary electrical layout and grid connection is then included for each grid. The equivalents are finalized by adding the total grid load for each case analyzed as geographically correctly distributed as possible.

The establishing of the computer grid equivalents and the preliminary electrical layout of the wind farms are detailed in the following sections.

The computer programme used in performing the Load Flow analysis is the power system computer package NEPLAN 2000 of Buzarello & Cott, Zurich. This is identical to the programme package purchased and handed over to ELECTRA after a two week intensive training period of two ELECTRA staff members at ELSAMPROJEKT A/S in May/June 1993 as part of the Step 1 wind farm electrical workshop equipment.

10.4 Computer equivalents of the ELECTRA grids

It has been agreed that the computer equivalents of the three ELECTRA grids shall be established for the year 1998 including all known and approved grid and power station extensions and including the planned new power station in Praia. The year 1998 has been selected as it is the most likely year for erecting the possible Step 2 wind farms.

All existing and planned and approved desalination plants up to 1998 are added to the equivalents as constant loads.

The extended wind farms included in the computer equivalents comprises a total number (Step 1 + Step 2) of 300 kW wind turbines as follows:

Praia :	12
Mindelo:	9
Sal:	4

These numbers have been chosen as "worst case" numbers in the sense that if the Load Flow analysis, based on wind farms this size, shows satisfactory results, then all smaller number of wind turbines in each wind farm can be accepted without any further investigations.

Please notice that the number of wind turbines assumed for this load flow analysis is larger than the final recommendations of this report.

10.4.1 Data Collection

With the purpose of establishing computerized grid equivalents of the ELECTRA power systems, data on the electrical grids of Sal, Mindelo and Praia have been collected during 4 field missions to the Cape Verde Islands, the first being during the RISØ/ELSAMPROJEKT feasibility study in 1989-90 leading to the Step 1 wind farms. The second, third and fourth field missions took place as part of this RISØ/ELSAMPROJEKT feasibility study for a possible Step 2 extension of the wind farms.

For each ELECTRA power system, grid maps and data including substations, underground cables, overhead lines, dimensions and types have been made available. Also the installed transformer capacity in each substation appear in these maps. Finally planned and confirmed grid reinforcements, changes, extensions and new substations as well as extensions in the power stations within the next 2-3 years have been added.

Most of these extended grid maps are drawn by hand (one using various colours in identifying different cable dimensions) and thus not suitable for reproduction in B&W and A4-scale in this report.

The sizes of the three ELECTRA power system computer equivalents, grid status 1998, are:

Number of -	Sal	Mindelo	Praia
Nodes	64	133	204
Cables/lines	30	73	109
Transformers	32	66	101
Capacitor banks	0	1	1
Generators	6	4	7
Wind turbines	4	9	12

10.4.2 Grid Measurements

As a consequence of not knowing the typical active (P) and reactive (Q) load on each grid substation transformer and thus not being able to determine the total geographical load distribution in each of the ELECTRA grids, a grid measuring programme has been performed during the RISØ/ELSAMPROJEKT field mission to Cape Verde in April/May 1993.

Steady state measurements of selected electrical parameters have been performed in a total of 4 suitable substations or directly at the power station outgoing feeders in each of the grids.

The measurement equipment used was 4 Power System Analyzers from the Italian company ELCONTROL named VIP System 3. See annex A. Each of these Power System Analyzers included three 1000 Amps current clamps and possibility of measuring voltage up to 600 V phase-phase AC directly.

These instruments were generally set up to log and printout 30 minute average values of the three phase active power, the three phase power factor, the phase-phase voltage of phase 1 - 2 and the phase-phase voltage of phase 2 - 3 of the selected feeders. Where this was not possible due to lack of voltage transformers, 30 minute average values of the current of phase 1, the current of phase 2, the phase to neutral voltage of phase 1 and the phase to neutral voltage of phase 2 were logged and printed out.

Furthermore, manual readings of the Watt meters of all outgoing feeders in the power station of Praia and Mindelo were performed every 30 minutes 24 hours a day by the local power station personnel.

Travelling from island to island on this 3 week mission approx. one week of data logging was performed on each grid.

The results of this grid measuring programme for determining the load distribution are shown graphically in annex E.

10.4.3 Geographical Load Distribution

As 4 simultaneous measurements in each of the ELECTRA grids of Praia, Mindelo and Sal can never reveal the full load distribution, discussions with ELECTRA staff members responsible for each of the three grids have been performed in order to use all of their experience and knowledge regarding the geographical load distribution of **all** existing and planned substations within a 3 year horizon. These discussions took place during the RISØ/ELSAMPROJEKT field mission to Cape Verde on April 28 - May 19 1993 and was repeated during the RISØ/ELSAMPROJEKT field mission to Cape Verde on September 12 - 28 1995.

During these discussions it was possible to estimate the total geographical load distribution for each grid thus providing, along with the performed measurements, the final input data for the resulting Load Flow analysis.

10.4.4 Final Grid Equivalents

By normalizing the total geographical distributed load to the maximum measured peak load during the measuring campaign in 1993, it is now possible to match the geographical load distribution to any load forecast by multiplying all normalized loads by a simple scale factor. This, in conjunction with the established grid models, comprises the computerized grid equivalents to which the existing and planned desalination plants are added as additional constant loads.

10.4.5 Selected Load Forecast

As a conservative approach, the maximum and minimum load for the year 1997 for each ELECTRA grid has been chosen for the Load Flow analysis, although the Load Flow grid equivalents are established for 1998 as the most likely year of erecting the possible Step 2 wind turbines. The 1997 loads are found in the load forecast prepared in section 7 in this report.

Maximum desalination load is assumed at minimum consumers' load so that the case of maximum wind power output and minimum consumers' load can be assessed at realistic diesel generator loading conditions. This is an operational question of low load diesel engine operation at technical minimum for some hours, before high load operation is necessary in order to burn off residues in the diesel engine combustion chambers.

The load forecast estimates the following minimum, average and maximum load for 1997 in the ELECTRA grids. To these the assumed desalination load is added :

	Min. (kW)	Avg. (kW)	Max. (kW)
SAL			
load	474	863	1467
desalination	440	440	440
total	914	1303	1907
MINDELO			
load	969	2935	6658
desalination	1020	1020	1020
total	1989	3955	7771
PRAIA			
load	2093	3805	6658
desalination	900	900	900
total	2993	4705	7558

To match these loads to the normalized geographical distributed loads of the computer equivalents of the Sal, Mindelo and Praia grids the following scale factors comply :

	Scale Factor Minimum Load	Scale Factor Average Load	Scale Factor Maximum Load
Sal	0.49895	0.90842	1.54421
Mindelo	0.24575	0.74436	1.71215
Praia	0.38638	0.70242	1.22909

The number of digits shown in these scale factors are necessary for the Load Flow computer programme to match exactly the prescribed total loads.

10.5 Wind farm preliminary design

The wind farms of Step 1 and the possible Step 2 extensions are assumed to include the previous mentioned number of wind turbines. The maximum power output for the expanded wind farms must be assessed for the purpose of worst case analysis:

The Step 1 wind turbines are the 300 kW NORDTANK NTK 300/31 type. For the possible Step 2 extensions data for the same type of wind turbines is assumed.

As the NORDTANK NTK 300/31 wind turbine is stall regulated, the maximum power output depends on the density of the air and thus depends on the altitude above sea level of each wind turbine site. This results in the following maximum power output of each wind turbine at the three sites:

Praia:	345 kW
Mindelo:	350 kW
Sal:	360 kW

The maximum power output of each wind farm then becomes:

	Step 1 (kW)	Step 2 (kW)	Total (kW)
Sal	2x360 (720)	2x360 (720)	4x360 (1440)
Mindelo	3x350 (1050)	6x350 (2100)	9x350 (3150)
Praia	3x345 (1035)	9x345 (3105)	12x345 (4140)

10.5.1 Wind farm preliminary layout

Based on experience on layout of several large modern wind farms in western europe, the three ELECTRA wind farms as constructed in Step 1 are proposed redesigned when extended with the number of wind turbines in a possible Step 2.

The existing Step 1 wind farms are designed with a high voltage power circuit breaker for *each* 300 kW wind turbine and transformer. The normal procedure is to protect the transformer solely by a high voltage fuse. The wind turbines in the Step 1 wind farms are connected to the wind farm main high voltage busbar in parallel. The normal procedure is to connect all wind turbines to the wind farm main high voltage busbar in series using so-called ring main units thus saving a substantial amount of high voltage cable.

Thus utilizing most of the existing high voltage power circuit breakers and connecting all wind turbines using ring main units in series to the main high voltage busbar the preliminary layout of the extended wind farms is reached. These layouts are shown in annex F.

The layouts results in one power circuit breaker in excess at the Mindelo and Sal wind farms. These should be kept as wind farm spare parts.

The existing grid connection high voltage cable of each wind farm has shown adequate for the extended wind farms by the Load Flow analysis.

The final grid connection of the expanded wind farms has been changed in the following way:

Praia: Extending the grid connection cable from the present connection point of substation 5. Julho with approx. 2000 m 3x1x95 mm² Cu. cable to the high voltage busbar of the old power station. This is due to the present practice of frequently load shedding by disconnecting the feeder connecting the substation 5. Julho thus disconnecting the wind farm in peak load situations !

Mindelo: As the grid is expected to be operated at the present voltage level of 6.3 kV and the existing wind farm grid connection is at 20 kV with a 1200 kVA, 20/6.3 kV step-down transformer, two additional 1200 kVA step-down transformers are added to cope for the expanded wind farm.

Sal: No changes.

Finally each wind turbine is assumed installed with capacitor banks for no-load reactive power compensation only.

10.5.2 Step 2 wind farms grid connection costs

The grd connection cost of the Step 2 expansion of the wind farms is based on the actual prices, May 1993, for similar equipment for the Step 1 wind farms. These prices have been multiplied with a rate of inflation of 3.5% for 1993/94 and 3.0% for 1994/95 resulting in the prices used for 1995. The price used for the ring main units is the actual 1995 price as paid in other new wind farms.

The following comprises the 1995 pricing for all high voltage equipment in each Step 2 wind farm expansion *excluding* the wind turbines themselves:

1995	Ring Main Unit		Step-up Trafo		Step-down Trafo		
Budget (1000 DKK)	No	Price	No	Price	No	Price	Wind Farm
Praia	12	720	9	765	0	0	1485
Mindelo	9	540	6	510	2	162	1212
Sal	4	240	2	170	0	0	410
Total	25	1500	17	1445	2	162	3107

1995 Budget (1000 DKK)	25 mm² cable		50 mm² cable		95 mm² cable		Wind Farm
	m	Price	m	Price	m	Price	
Praia	1000	171	1400	243	2000	350	764
Mindelo	650	112	100	17	1600	280	409
Sal	400	69	200	35	0	0	104
Total	2050	352	1700	295	3600	630	1277

The total grid connection budget in 1995 prices for each Step 2 wind farm expansion becomes:

1995 Budget (1000 DKK)	Ring main units & Transformers	High voltage Cables	Wind farm Total
Praia	1485	764	2249
Mindelo	1212	409	1621
Sal	410	102	514
Total	3107	102	4384

It is stressed that the above grid connection budget prices are for the Step 2 wind farm expansions assumed for the load flow analyses, i.e. Step 2 wind farms with 2x300 kW wind turbines at Sal, 6x300 kW at Mindelo and 9x300 kW at Praia. Step 2 expansions with fewer wind turbines would give reduced total costs for grid connection.

10.6 Load Flow Analysis

In this section the selected steady state Load Flow cases and the results of the analysis are presented.

10.6.1 Cases Analyzed

Load Flow calculations have been performed for each of the three ELECTRA power system grid equivalents, as described in the previous sections, for the following worst cases:

1F : Maximum grid load. Maximum wind farm production. This case results in the highest possible voltages at the wind turbine terminals. The wind turbine step-up transformers are therefore regulated to give a voltage of 420 V at the wind turbine side of these transformers. This transformer tap position is then kept unchanged in all cases analyzed as will be the case if the Step 2 wind farms are constructed.

2F : Maximum grid load. No wind farm production. The wind farms are assumed electrical connected to the grid but each wind turbine is disconnected due to a no wind situation. This case results in the lowest possible voltages at the low voltage side of the wind turbine step-up transformers.

3F : Minimum grid load. Only the number of wind turbines are connected which is allowed due to the necessary technical minimum production of the diesel engines in operation as the minimum required spinning capacity. This is discussed in section 9 and results in:

Praia:	maximum 1720 kW (5 wind turbines á 345 kW) wind farm production.
Mindelo:	maximum 1150 kW (3 wind turbines á 350 kW) wind farm production.
Sal:	maximum 500 kW (2 wind turbines á 250 kW) wind farm production.

10.6.2 Results

Load Flow computations typically generate large amounts of computer printouts for which reason the results have been compressed in tables for each of the ELECTRA grids analyzed. These tables are placed in annex G. In these tables the production of active (P) and reactive (Q) power from the power stations and the expanded wind farms can be seen together with the total load and the grid losses. From these results the power factor (cosφ) for the power system have been computed. Selected busbars showing the critical wind farm voltages are presented. These busbars have names according to the wind farm layout drawings in annex F. Finally the relative voltage rise across the wind farm grid connection underground cables are calculated along with the power losses in these cables.

10.6.2.1 Praia Grid

The high voltage grid of Praia is dominated by a 3.5 km, 15 kV double ring system of 3x1x95 mm² Cu underground cables. The remaining system is a widely distributed rapidly growing 15 kV underground cable grid. To this system a new power station of 2 x 3 MVA diesel generator units is assumed connected to the old power station high voltage busbar by a 6 km double system of 3x1x95 mm² Cu underground cables. The old power station diesel generator units are then assumed only to be operated in peak load situations with low wind farm production. The Load Flow analysis has shown that this results in an unacceptable low voltage on the old power station main high voltage busbar. In the Load Flow analysis an -1600 kVAr capacitor bank therefore has been connected to this busbar producing the necessary voltage support at high load situations. It can be strongly argued, that the necessity of this capacitor bank is released by the introduction of the new power station, and thus it is not regarded as part of the wind farm Step 2 high voltage equipment.

In the result table for Praia in annex G the grid losses of reactive power varies from -733 kVAr to -1320 kVAr indicating that the 8.7 km, 20 kV, 3x1x95 mm² Cu wind farm grid connection cable is producing a surplus of capacitive reactive power. It is also observed that the grid power factor is maintained at approx. 0.89 at the maximum load situation with no wind farm production and no capacitor bank connected. The power factor reaches a value of approx. 0.93 at the minimum load situation with no capacitor bank included. Therefore no additional capacitor banks should be installed to compensate for the full-load reactive power demand of the wind turbine generators. This is provided for by the reactive power production of the grid connection and wind farm high voltage underground cables.

The voltage rise across the wind farm grid connection cable is fully acceptable (2.77%) at maximum wind turbine production with a total loss of power in the grid connection cables of 124 kW.

It is observed from the Praia result table that no critical steady state high or low voltages have been detected in the Mindelo wind farm and grid connection.

10.6.2.2 Mindelo Grid

The high voltage grid of Mindelo is a widely distributed 6.3 kV underground cable city grid. Utilizing the 20 kV wind farm grid connection cable, the airport of St. Vicente and two small villages are in the process of being connected to the Mindelo city grid along with a major industrial area close to the wind farm site. These grid expansions are assumed completed in 1997/98 (probably in 1996). The Mindelo city grid is still assumed operated at 6.3 kV in 1997/98.

The Load Flow analysis has shown that even with the surplus production of capacitive reactive power by the wind farm grid connection cable, unacceptable low voltages occurs in the Mindelo 6.3 kV city grid even in the case of maximum power station production and no wind farm production. In the Load Flow analysis an -2000 kVAr capacitor bank therefore has been connected to the power station 6.3 kV busbar producing the necessary voltage support at high load situations. It can be strongly argued, that the necessity of this capacitor bank is released only by the low voltage level of 6.3 kV at which the Mindelo city grid is still assumed operated, and thus the capacitor bank is not regarded as part of the wind farm Step 2 equipment.

In the Mindelo result table in annex G, the grid losses of reactive power varies from -300 kVAr to -761 kVAr indicating that the 11.5 km, 20 kV, 3x1x95 mm² Cu wind farm grid connection cable itself is producing a surplus of capacitive reactive power. It can also be observed that the grid power factor is maintained at high values ranging from 0.913 to 0.940 at both maximum and minimum load situation when introducing the -2000 kVAr capacitor bank. Thus no additional capacitor banks should be installed to compensate for the full-load reactive power demand of the wind turbine generators. This is provided for by the grid connection underground cable itself.

The voltage rise across the long wind farm grid connection cable is fully acceptable (1.02%) at maximum wind turbine production with a total loss of power of only 32 kW in this cable.

The voltage rise across the grid connection cable is negative (-0.41%) in the maximum load, no wind farm production case. The low loss of power and the negative voltage rise in the grid connection cable to the Mindelo city grid is caused by the fact that in the state of 1997/98, part of the wind farm production flows towards the airport, the industrial area and the two villages all of which are connected directly to the wind farm 20 kV main busbar by a new high voltage cable grid in the geographical opposite direction.

It can be observed from the Mindelo result table that no critical high or low voltages have occurred within the Mindelo wind farm and grid connection.

10.6.2.3 Sal Island.

The high voltage grid of the Sal island is dominated by a 27 km long 13.8 kV, 3x50 mm² AL underground cable connecting the village of Santa Maria and the surrounding beach resort area at the southern tip of the island with the power station in the village of Palmeira. This cable itself generates -468 kVAr (capacitive reactive power) under no-load conditions ($Q = -U^2\omega C$). Therefore it is not surprising that the power factor of the Sal grid is very high in all load situations.

In the result table for Sal in annex G, the reactive grid losses vary from -410 kVAr to -516 kVAr indicating that the grid itself is producing a surplus of capacitive reactive power. Furthermore the high voltage cables in the wind farm itself and the 1.5 km grid connection cable generate an additional -130 to -200 kVAr. It is also observed that the grid power factor is maintained at its very high level (0.894 - 0.985) in all cases analyzed. Thus no additional capacitor banks are necessary to compensate for the full-load reactive power demand of the wind turbine generators.

The voltage rise across the wind farm grid connection is insignificant (0.03%) at full wind turbine production with a loss of power of 3 kW in this cable.

The voltage at the outermost end of the 13.8 kV cable grid, the Aeroflot hotel at Santa Maria, is also at an acceptable value of 13.2 kV in the maximum load situation.

Finally it can be observed from the Sal result table that no critical high or low voltages have occurred at the wind farm.

11. Power system reliability

Probabilistic methods are commonly used for calculation of the long run indexes for the power system reliability. There exists a range of such indexes which all have their advantages and disadvantages in ways of presenting the long run expectation of the power availability. For this study, the loss of load expectation (LOLE) is used. LOLE is an index for the power availability commonly used by the power utilities typically in connection with power generation expansion planning.

11.1 Loss of load expectation

The loss of load expectation is the expected total duration of any power supply shortage within a specific period. A power supply shortage occurs when the available power generating capacity is less than the demand. The LOLE may be calculated as follows (in hours per year):

$$LOLE = \sum_{i=1}^{N} T_i \cdot \Pr(P_{m,i} < 0)$$

Here, N is the number of time periods (hours) of duration T_i in one year, and $Pr(P_{m,i} < 0)$ is the probability that the generating capacity margin $P_{m,i}$ in T_i is less than zero.

The impact of the wind generated power is - when for the sake of simplicity assuming the calculations to be performed in the time-domain - included by adjusting the consumer load to the net load, and further by defining the generating capacity margin $P_m(t)$ as the difference between the available conventional capacity $P_c(t)$ and the net load:

$$P_m = P_c(t) - P_n(t)$$

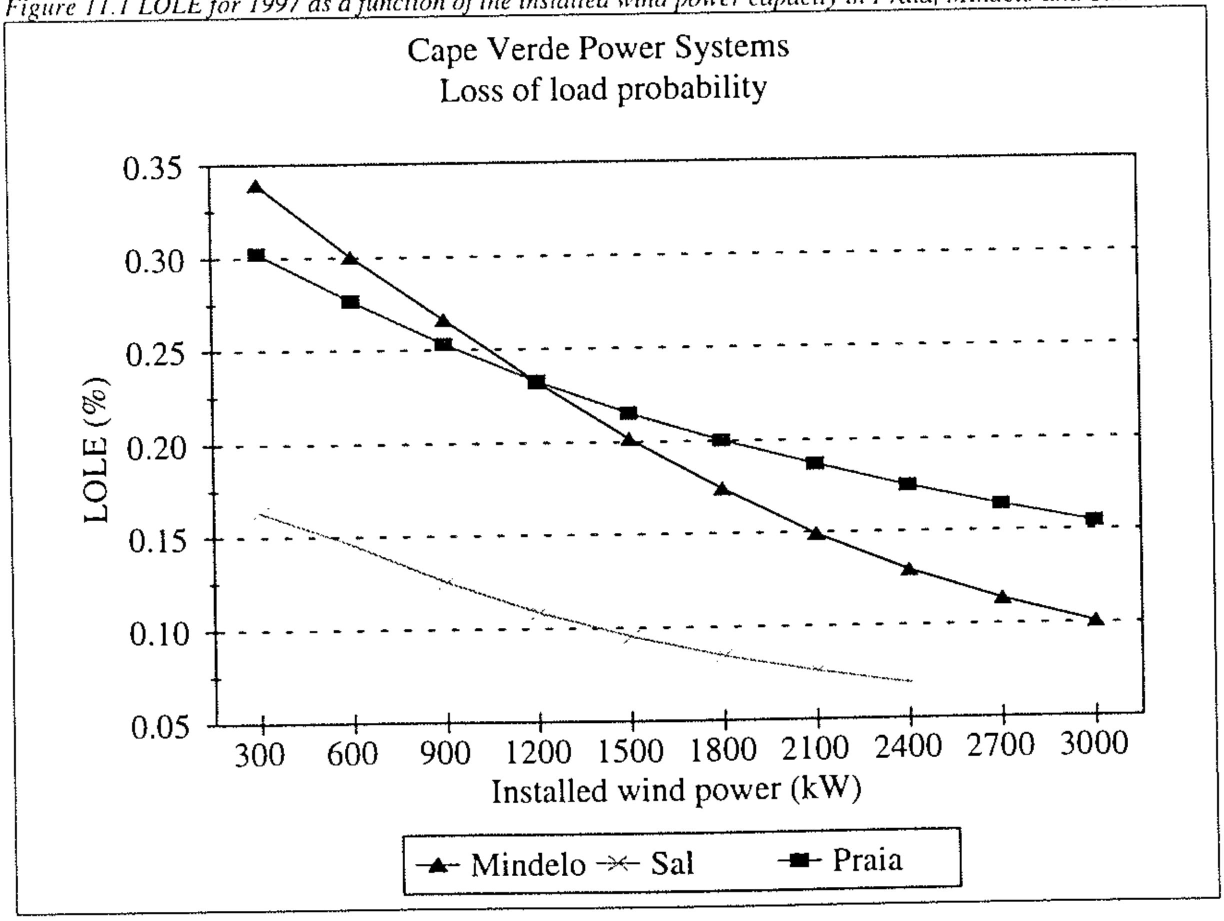
The net load is the difference between the consumer loads including line losses and the wind power output. $Pr(P_{m,i} < 0)$ may be calculated for each time frame by using standard statistical methods as described in /3/, /4/ and /15/ (enclosed as appendix O).

Assuming power system data as specified in table 11.1, the loss of load expectation is calculated for Praia, Mindelo and Sal for 1997 as a function of the installed wind power capacity. The wind energy utilization factor is here assumed to be 1.0 as it is assumed that in case of a loss of load situation, all available wind energy is utilized. The result of the LOLE calculations is shown in figure 11.1. It is seen that the loss of load expectation is reduced due to the installed wind power capacity. With only the Step 1 wind turbines, the LOLE is close to 0.25 % for Praia and Mindelo and below 0.15 % for Sal.

Table 11.1 Power system specifications assumed for 1997 for calculation of loss of load expectation.

	Praia	Mindelo	Sal
Diesel capacity (kW)	2500	3168	1000
	2650	3168	1000
	2650	2300	1000
	2514	2300	500
	1560		500
Diesel availability	0.9	0.9	0.9
Min load (kW)	2700	2500	1100
Max load (kW)	7000	5000	1700
Wind turbine type	NTK 300 kW	NTK 300 kW	NTK 300 kW
Wind speed scale parameter (m/s)	9.0	11.8	8.4
Wind speed shape parameter	3.52	4.05	3.64
Air density (kg/m^3)	1.14	1.17	1.18
Performance factor	0.99	0.99	0.99
Site factor	1.00	1.00	1.00
Technical availability factor	0.95	0.95	0.95
Electric transmission losses factor	0.98	0.98	0.98
Utilization factor	1.00	1.00	1.00

Figure 11.1 LOLE for 1997 as a function of the installed wind power capacity in Praia, Mindelo and Sal.

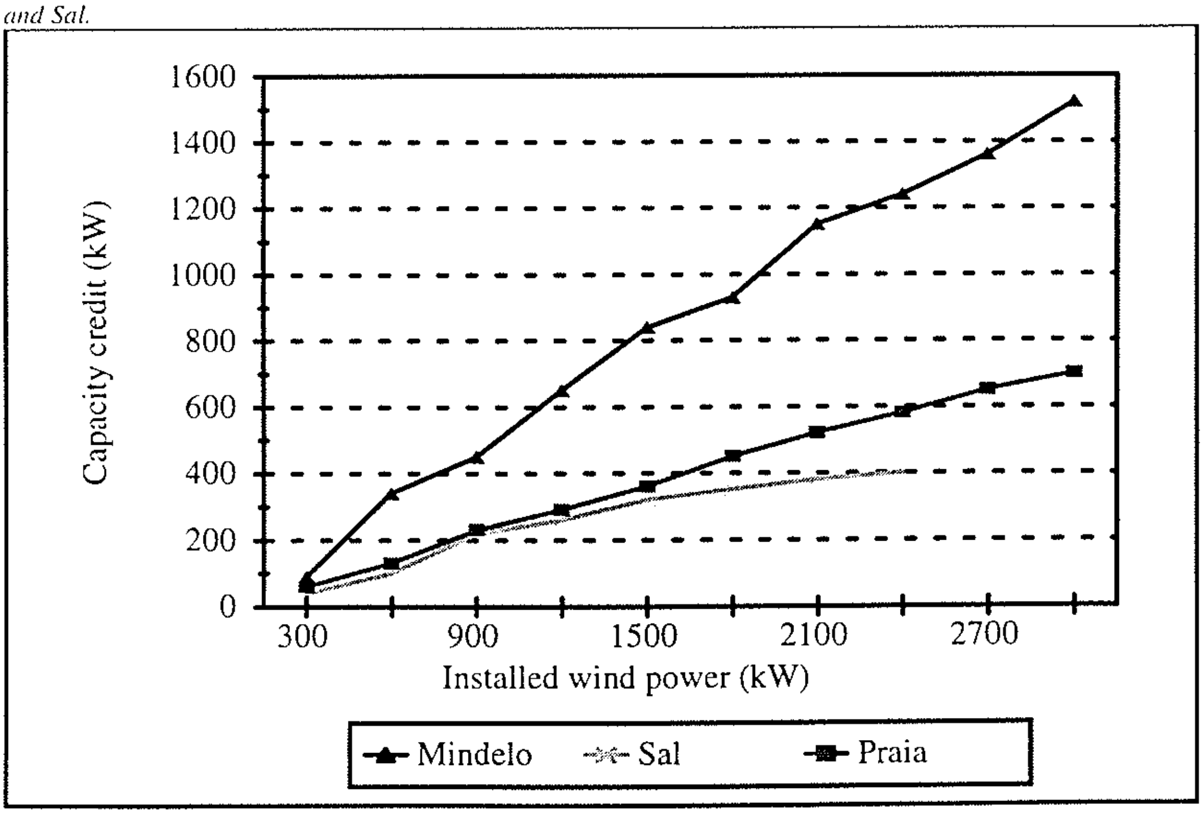


11.2 Wind power capacity credit

As the power system reliability is increased by the introduction of wind power, a fraction of the wind power can be assumed to be firm power, ie. the wind turbines may be assigned a capacity credit. The wind turbines capacity credit may be estimated by finding the amount of conventional diesel capacity that must be installed instead of the wind turbines as to obtain the same LOLE. In systems with high wind power penetration, the wind power fluctuations may be significant and should be taken into account. Taking the approach as described in /15/ (enclosed as appendix O), figure 11.2 shows the estimated firm wind power capacity or wind power capacity credit as a function of the installed wind power capacity for the power systems of Praia, Mindelo and Sal of 1997.

Assuming a total (step 1 + 2) of nine 300 kW wind turbines at Praia, seven at Mindelo and four at Sal, the firm wind power capacity as can be read from figure 11.2 is 650 kW, 1150 kW and 260 kW. Relative to the installed wind power the corresponding figures are 24, 45 and 21 %. The difference in capacity credit per installed kW wind power between the three sites is firstly explained by the difference in wind resources. Thus, with the assumed wind resources and further specifications as given in table 11.1, the annual average wind power output relative to the installed wind power capacity becomes about 31 % for Praia, about 58 % for Mindelo and about 28 % for Sal giving a ratio between the capacity credit and the average output in the range of 0.75 and 0.78. It should be noted that for large systems with marginal amounts of wind energy only, the capacity credit of the wind turbines are often assumed to be equal to the annual average output power.

Figure 11.2 Wind power capacity credit as a function of the installed wind power capacity for Praia, Mindelo and Sal.



12. Power system operation

The power systems with and without the Step 2 wind farms has been analyzed in terms of operation and performance using the power system performance model WINSYS. WINSYS is described in annex H. The following sub-sections give the basic assumptions, the Step 2 wind farms energy output, as well as the Step 2 wind farms impact on the fuel consumption and operation time of the diesel power plants. Detailed result and input printouts from WINSYS are found in annex I, J and K for Praia, Mindelo and Sal respectively.

12.1 Basic assumptions

Basically, the Step 2 wind farms are viewed as an extension of the existing Step 1 wind farms. The sites and wind resources are assumed as given in section 8. In case the wind power output must be limited, e.g. during high wind and low load periods, this is assumed to be managed by a simple control system as discussed in section 9.

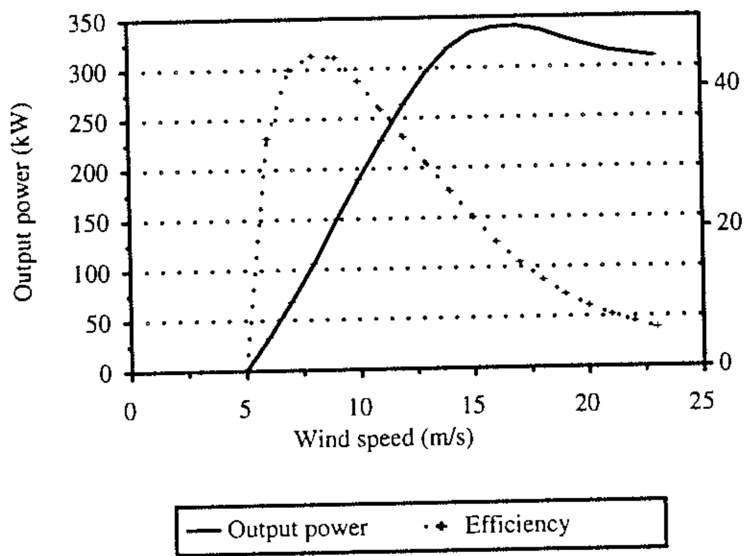
The power system operation strategy is assumed to be unchanged for the lifetime period of the wind turbines. The following power system operation strategy parameters for Praia, Mindelo and Sal are assumed:

- The capacity load margin, k_{lm} is set to 5 % of the installed spinning capacity. The definition of the capacity load margin is given in section 9. The 5 % margin gives a simulated operation strategy without wind power close to the actual operation strategy in both Praia, Mindelo and Sal.
- The capacity wind margin, k_{wm} is set to 30 % of the installed wind power capacity. The definition of the capacity wind margin is given in section 9. Assuming the firm capacities and average outputs as estimated in section 11, the capacity wind margin becomes 24 % for Praia, 32 % for Mindelo and 22 % for Sal. Changing the wind margin down, e.g. down from 30 to 24 % for Praia would give simulation results indicating higher savings due to the wind turbines and vice versa.
- The wind turbine stand alone margin is set to 100 % of the installed wind power capacity, i.e. the wind turbines are assumed to operate only together with the diesel power plant.

In the analysis of the power system operation, the Step 2 wind turbines are assumed to be similar to the Step 1 wind turbines, i.e. Nortank 300 kW turbines with performance as specified in figure 12.1. In reality the wind turbines may not necessarily have to be Nordtank 300 kW, but could be any size that could be erected by the use of the available crane procured by Step 1.

The load consists of consumer loads including grid losses and desalination loads. The annual development in consumer loads and desalination is assumed as specified in section 7. Hour by hour variations as well as seasonal variations are analyzed using readings of actual hour by hour consumer and desalination loads from Electra power plant logbooks in 1991, 1992 and 1993. The data analysis indicate that the desalination load may be considered to be constant over the year, whereas the consumer loads can be described by the consumer load profiles as shown in Figs. 7.1 - 7.6.

Figure 12.1 Assumed wind turbine power curve and efficiency at standard air density conditions. Wind turbine rated power is 300 kW, hub height is 30.5 m, rotor diameter is 31 m.



The development in diesel capacity is assumed to be as described in section 7. The assumed technical specifications of the individual diesel generator sets are based on actual manufacturer data and communications as well as performance statistics from Electra. Tables 12.1 - 12.3 are for development scenario A, and tables 12.4 - 12.6 are for scenario B.

Re. technical minimum load, this is assumed to be 40 % of rated capacity for all heavy fuel units and 25 % of rated capacity for all gas-oil units. The exception is the G3 gas-oil generator at Sal, which for particular reasons can only be operated down to 40 % of rated capacity.

Re. fuel consumption, model inputs for specifying the fuel consumption curve of the individual diesel generators have been calibrated to match the actual fuel consumption for the period January to June 1995, see also appendix N. It should be noted that the actual specific fuel consumption is higher than the manufacturer specifications. As it appears from the data in appendix C, the annual average fuel efficiency in 1994 was 33 % for Praia, 37 % for Mindelo and 35 % for Sal, whereas e.g. manufacturer data for the 9M453C MAK diesel generators as installed in Mindelo specifies a specific fuel consumption ranging from 181 to 192 g/kWh corresponding to a fuel efficiency between 44 and 47 % assuming a fuel heat value of 42700 kJ/kg or 11.86 kWh/kg. This fact that the actual operation is less efficient than the manufacturer data is reflected also for the assumed fuel consumption of the future diesel generators. Thus, the future diesel generators are assumed to be more efficient than the existing, but still less efficient than can be read from manufacturer data.

The fuel types assumed are heavy fuel and gas oil. The heavy fuel is assumed to have a heat value of 11.38 kWh/kg and a density of 0.96 kg/l. The gas oil is assumed to have a heat value of 11.86 kWh/kg and a density of 0.84 kg/l.

Table 12.1 Assumed Scenario A Praia diesel power plant generator set specifications.

Generator set	N11	N10	N9	N8	N7	N6	N5	N4	N3	N2	N1	MAK	MAK	Deutz	Deutz	Movel
Commissioned	2018	2018	2010	2006	2004	2003	2001	2001	1998	1998	1996	1991	1992	1987	1982	1986
Decommissioned	2038	2038	2030	2026	2024	2023	2021	2021	2018	2021	2021	2021	2021	2003	1998	1996
Rated capacity (kW)	2400	2400	5000	5000	5000	5000	3000	3000	3000	3000	2500	2650	2650	2514	1560	600
Tech. min. load (%)	40	40	40	40	40	40	40	40	40	40	40	40	40	25	25	25
Fuel type	heavy	heavy	heavy	heavy	heavy	heavy	heavy	heavy	heavy	heavy	heavy	heavy	heavy	gas oil	gas oil	gas oil
Full load fuel efficiency (%)	40	40	40	40	40	40	38	38	38	38	36	36	36	36	34	36
No load consumption (% of full load)	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5

Table 12.2 Assumed Scenario A Mindelo diesel power plant specifications.

Generator set	N11	N10	N9	N8	N7	N6	N5	N4	N3	MAK	MAK	Deutz	Deutz	Deutz	Deutz	Movel
Commissioned year	2019	2019	2014	2014	2006	2004	2004	1999	1999	1994	1994	1984	1977	1971	1968	1989
Decommissioned year	2039	2039	2034	2034	2026	2024	2024	2019	2019	2014	2014	2004	1999	1994	1988	1994
Rated capacity (kW)	2400	2400	3300	3300	2400	2400	2400	2400	2400	3168	3168	2300	2300	1000	1000	600
Tech. min. load (%)	40	40	40	40	40	40	40	40	40	40	40	40	25	25	25	25
Fuel type	heavy	heavy	heavy	heavy	heavy	heavy	heavy	heavy	heavy	heavy	heavy	heavy	gas oil	gas oil	gas oil	gas oil
Full load fuel efficiency (%)	38	38	38	38	38	38	38	38	38	38	38	36	35	34	34	34
No load consumption (% of full load)	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5

Table 12.3 Assumed Scenario A Sal diesel power plant specifications.

Generator set	N9	N8	N7	N6	N5	N4	N2	N1	Cum-mins	Deutz	Cum-mins	Cum-mins	DAF	DAF	Movel
Commissioned year	2017	2014	2010	2007	2005	2003	1997	1997	1990	1994	1983	1983	1990	1990	1994
Decommissioned	2037	2034	2030	2027	2025	2023	2017	2017	2010	1997	2003	2003	1995	1995	1997
Rated capacity (kW)	2000	1000	1000	1000	1000	1000	1000	1000	1000	400	500	500	200	200	600
Tech. min. load (%)	25	25	25	25	25	25	25	25	40	25	25	25	25	25	25
Fuel type	gas oil	gas oil	gas oil	gas oil	gas oil	gas oil	gas oil	gas oil	gas oil	gas oil	gas oil	gas oil	gas oil	gas oil	gas oil
Full load fuel efficiency (%)	38	38	38	38	38	38	38	38	33	36	34	34	34	34	36
No load consumption (% of full load)	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5

Table 12.4 Assumed Scenario B Praia diesel power plant generator set specifications.

Generator set	N11	N10	N9	N8	N7	N6	N5	N4	N3	N2	N1	MAK	MAK	Deutz	Deutz	Movel
Commissioned	2018	2018	2010	2006		2003		2001	1998	1998	1996	1991	1992	1987	1982	1986
Decommissioned	2038	2038	2030	2026		2023		2021	2018	2021	2021	2021	2021	2003	1998	1996
Rated capacity (kW)	2400	2400	5000	5000		5000		3000	3000	3000	2500	2650	2650	2514	1560	600
Tech. min. load (%)	40	40	40	40		40		40	40	40	40	40	40	25	25	25
Fuel type	heavy	heavy	heavy	heavy		heavy		heavy	heavy	heavy	heavy	heavy	heavy	gas oil	gas oil	gas oil
Full load fuel efficiency (%)	40	40	40	40		40		38	38	38	36	36	36	36	34	36
No load consumption (% of full load)	5	5	5	5		5		5	5	5	5	5	5	5	5	5

Table 12.5 Assumed Scenario B Mindelo diesel power plant specifications.

Generator set	N11	N10	N9	N8	N7	N6	N5	N4	N3	MAK	MAK	Deutz	Deutz	Deutz	Deutz	Movel
Commissioned year	2019	2019	2014	2014		2004		1999	1999	1994	1994	1984	1977	1971	1968	1989
Decommissioned year	2039	2039	2034	2034		2024		2019	2019	2014	2014	2004	1999	1994	1988	1994
Rated capacity (kW)	2400	2400	3300	3300		2400		2400	2400	3168	3168	2300	2300	1000	1000	600
Tech. min. load (%)	40	40	40	40		40		40	40	40	40	40	25	25	25	25
Fuel type	heavy	heavy	heavy	heavy		heavy		heavy	heavy	heavy	heavy	heavy	gas oil	gas oil	gas oil	gas oil
Full load fuel efficiency (%)	38	38	38	38		38		38	38	38	38	36	35	34	34	34
No load consumption (% of full load)	5	5	5	5		5		5	5	5	5	5	5	5	5	5

Table 12.6 Assumed Scenario B Sal diesel power plant specifications.

Generator set	N9	N8	N7	N6	N5	N4	N2	N1	Cum-mins	Deutz	Cum-mins	Cum-mins	DAF	DAF	Movel
Commissioned year	2017		2010		2005	2003	1997	1997	1990	1994	1983	1983	1990	1990	1994
Decommissioned	2037		2030		2025	2023	2017	2017	2010	1997	2003	2003	1995	1995	1997
Rated capacity (kW)	2000		1000		1000	1000	1000	1000	1000	400	500	500	200	200	600
Tech. min. load (%)	25		25		25	25	25	25	40	25	25	25	25	25	25
Fuel type	gas oil		gas oil		gas oil	gas oil	gas oil	gas oil	gas oil	gas oil	gas oil	gas oil	gas oil	gas oil	gas oil
Full load fuel efficiency (%)	38		38		38	38	38	38	33	36	34	34	34	34	36
No load consumption (% of full load)	5		5		5	5	5	5	5	5	5	5	5	5	5

12.2 Wind farms energy output

Applying the basic assumptions as specified in section 12.1, the potential output, $E_{w,pot}$ (MWh/year) of the wind farms may be calculated.

$$E_{w,pot} = 8766 \cdot N_{wt} \int_0^{\infty} p(u) \cdot f(u)\ du$$

Here N_{wt} is the number of equal wind turbines in the wind farm, $p(u)$ is the site specific power curve and $f(u)$ is the wind speed distribution. As the wind turbines assumed are stall regulated, their performance is proportional to the air density, i.e. the power curve at standard air density should be scaled to match the actual site specific power curve:

$$p(u) = p(u)_{std} \cdot \frac{\rho}{1.225}$$

Here ρ is annual average air density at the site which may be calculated from the temperature, T (deg. C) and air pressure, B (mBar).

$$\rho = 1.225 \cdot \frac{288.15}{T + 273.15} \cdot \frac{B}{1013.3}$$

Following the recommendations of IEA /5/, the annual utilized energy output, AUE_t may be adjusting the potential output with a number of correction factors.

$$AUE_t = E_{w,pot} \cdot k_{per,t} \cdot k_{site,t} \cdot k_{ava,t} \cdot k_{los,t} \cdot k_{util,t}$$

Here:
- $k_{per,t}$ is the performance factor to take account for rain, dirt, wear and tear, etc. reducing the performance of the wind turbines,
- $k_{site,t}$ is the site factor to take account for e.g. wind shadow effects in wind parks,
- $k_{ava,t}$ is the resulting technical availability factor including both the impact of wind turbine outages due to maintenance and repairs as well as grid availability,
- $k_{los,t}$ is the electric transmission losses factor depending on the electric losses between the wind turbines and the point of common connection (grid connection point),
- $k_{util,t}$ is the utilization factor to take account for that some of the energy output may not be utilized during periods with high wind and low load.

In the calculations of the annual energy output from the Step 2 wind farms, all the correction factors except for the utilization factor is assumed to be independent on the wind power penetration. The performance factor is assumed to be 0.99 assuming the wind turbines to be well maintained during their lifetime, and assuming dirt on the blades to have only limited effect on the performance. The site factor is assumed to be 1.0. No reduction due to wake is assumed as the wind turbines are suggested to be placed in one row perpendicular to the prevailing wind direction, and as seen from section 8, for all sites over 90 % of the wind energy is expected to be in the prevailing direction. The technical availability factor is assumed to be 0.95. This is lower than experienced in e.g. Denmark, and is as such assumed to be a conservative estimate of the technical availability factor. The electric transmission losses (or site facility losses) factor is assumed to be 0.97 for Praia and Mindelo, and 0.99 for Sal. In reality, as it appears from Figs. 12.2 - 12.4 based on the electric grid analysis in section 10, the losses depend on the wind farm sizes as well as the load development. It should be noted that for the Step 2 wind farm sizes investigated, the transmission losses factors assumed are considered as rather on the conservative side.

As the investigated Step 2 wind farms together with the Step 1 is assumed to supply a significant part of the energy consumption, special attention is paid on the estimation of the wind energy utilization factor. The utilization factor may be less than unity as wind energy must be dissipated in case:

$$P_l(t) - P_w(t) < P_{\min}(t)$$

Here is $P_l(t)$ the consumers load, $P_w(t)$ the wind power output and $P_{min}(t)$ the technical minimum load of the conventional power plant. The technical minimum load depends on the conventional spinning capacity, and detailed simulations of the power system operation have been prepared using WINSYS in order to determine the dissipated wind energy year by year during the Step 2 wind farms life time. For scenario A, Figs. 12.5 - 12.7 show the relation between the annualized energy output and the installed wind power capacity, whereas Figs. 12.8 - 12.10 show the year by year energy output for 6 x 300 kW Step 2 wind turbines in Praia, 4 x 300 kW Step 2 wind turbines in Mindelo and 2 x 300 kW Step 2 wind turbines in Sal. Figs. 12.11 - 12.13 show the corresponding values for scenario B. As it appears from the figures, the amount of energy to be dissipated depends on the wind energy penetration.

Figure 12.2

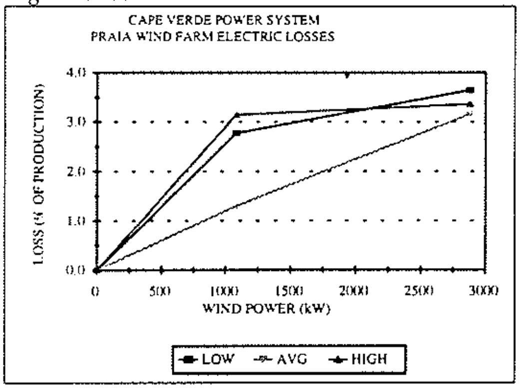


Figure 12.5

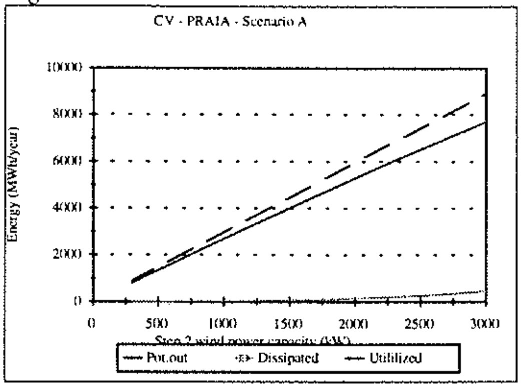


Figure 12.3

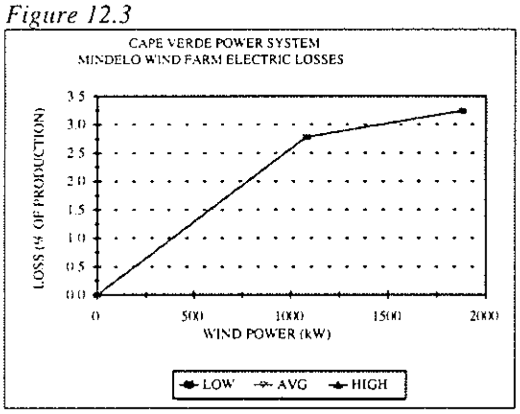


Figure 12.6

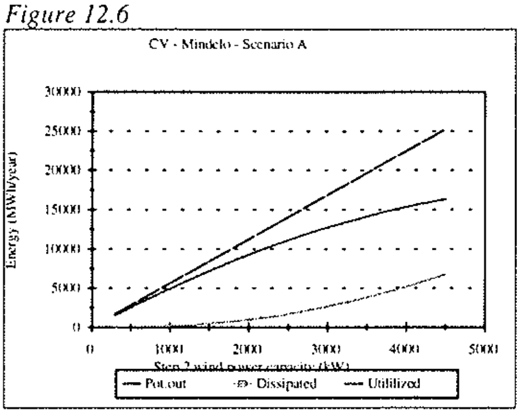


Figure 12.4

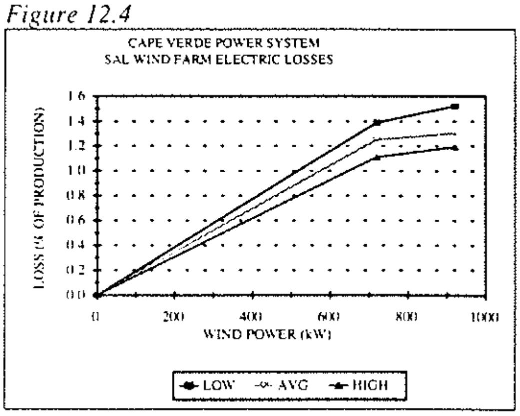


Figure 12.7

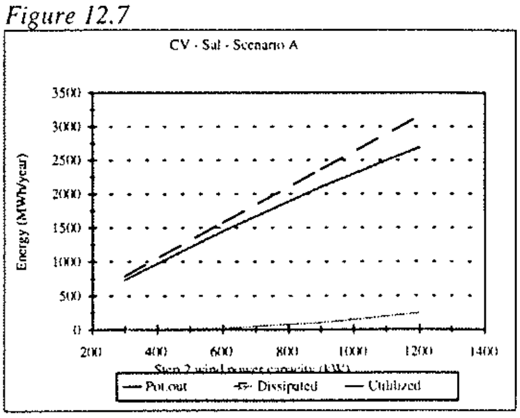


Figure 12.8

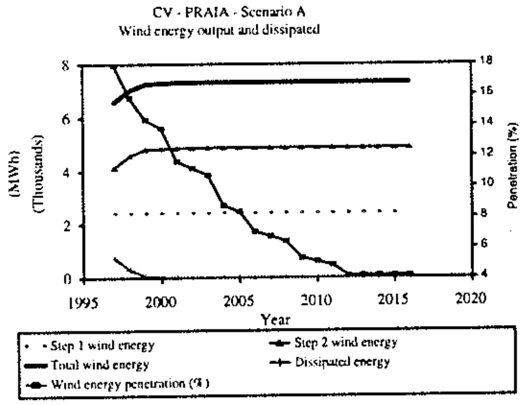


Figure 12.9

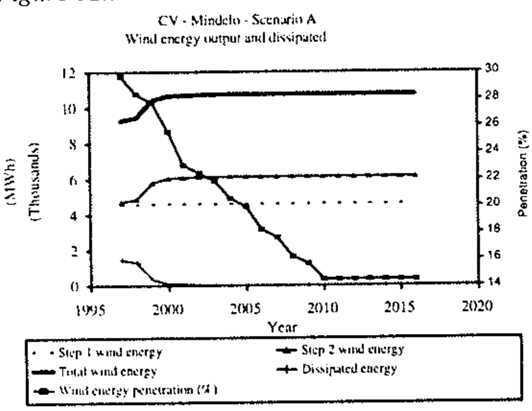


Figure 12.10

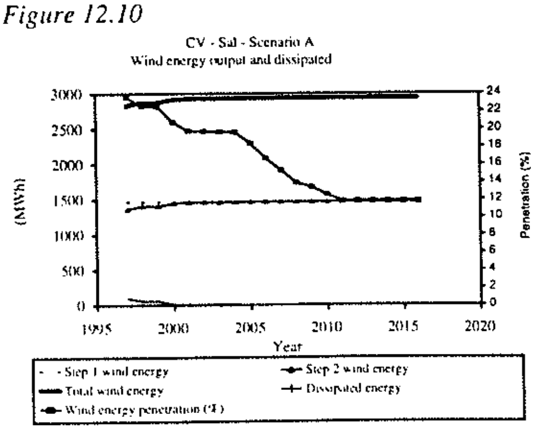


Figure 12.11

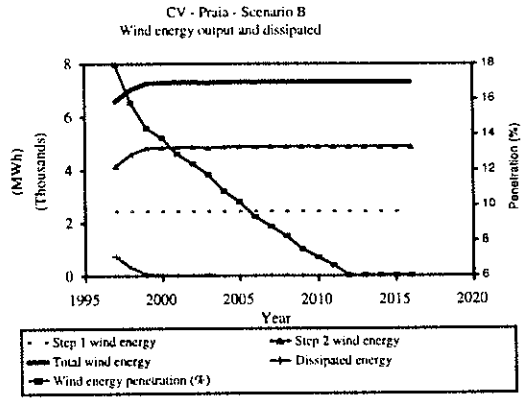


Figure 12.12

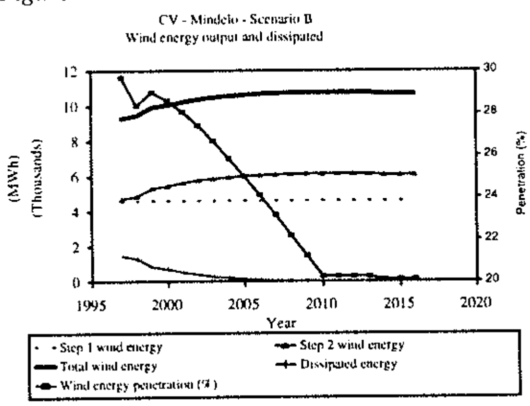
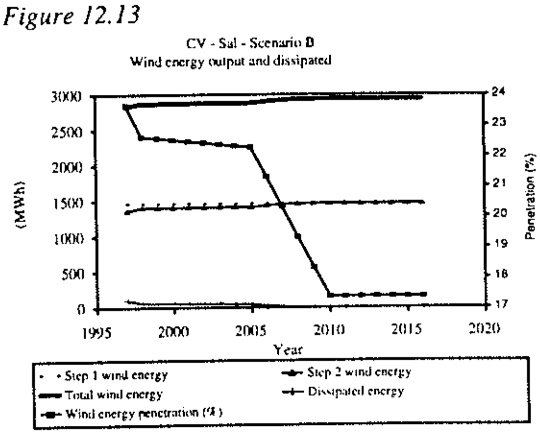


Figure 12.13



12.3 Fuel savings

The fuel consumption curve in [l/h] for a specific genset may normally be approximated reasonably well by a linear function of the load. Assuming this, the fuel consumption per hour of more gensets, N, sharing the load may be expressed as:

$$F = \sum_{i=1}^{N} F_{0,i} + \alpha_{g,i} \cdot P_{g,i}$$

and the fuel consumption in a period T becomes:

$$TF = \int_{0}^{T} F dt$$

Here is:
N the number of spinning generators,
$F_{0,i}$ [l/h] the no load consumption of genset i,
$\alpha_{g,i}$ [l/kWh] the fuel consumption slope, and
$P_{g,i}$ [kW] the load on genset i.

WINSYS calculates the fuel savings due to the Step 2 wind farms as the difference between the simulated fuel consumption for the existing power system with the Step 1 wind farms and the system expanded with the Step 2 wind farms. The fuel savings are calculated for each year of the wind farms operation taking account for load development and installation of new diesel generator sets and power plants.

For scenario A, figs. 12.14 - 12.16 show levelized fuel consumption as a function of the installed Step 2 wind power capacity. It is seen that the fuel consumption is reduced as a function of the installed Step 2 wind power capacity. The reduction in fuel consumption per installed kW wind power is larger for the first wind turbines than for the latter. This is basically because at high wind energy penetration some of the wind turbines output energy can not be utilized.

Assuming six 300 kW Step 2 wind turbines in Praia, four in Mindelo and two at Sal, WINSYS calculations give the year by year fuel consumption and savings due to the Step 2 wind farms as shown in figs. 12.17 - 12.19 for scenario A, and as shown in figs. 12.20-12.22 for scenario B. For both scenarios, it is seen that the fuel consumption is increasing from year to year. This is due to the assumed load development. The fuel savings are relative unchanged from year to year.

Figs 12.23-12.25 and 12.26 - 12.28 show the specific fuel consumption and saving due to the Step 2 wind farms for scenario A and B respectively. It is seen that without wind power in the system, the specific fuel consumption is reduced from year to year as more efficient diesel generator sets are assumed to be set in operation. With wind energy, the specific fuel consumption, i.e. tons of fuel consumed per year divided by the consumers annual load, is reduced depending on the wind energy penetration. As the load increases over the years, the wind energy penetration becomes less and the specific fuel consumption with wind energy is increasing towards the specific fuel consumption without wind energy. The specific fuel savings due to the Step 2 wind farms, i.e. annual fuel savings in tons divided by the annual utilized energy output from the Step 2 wind farms, is reduced from the first years to the latter as the assumed increased diesel generator efficiencies has a higher impact than the increment in utilized wind energy output due to less dissipation as the load increases over the years.

Figure 12.14

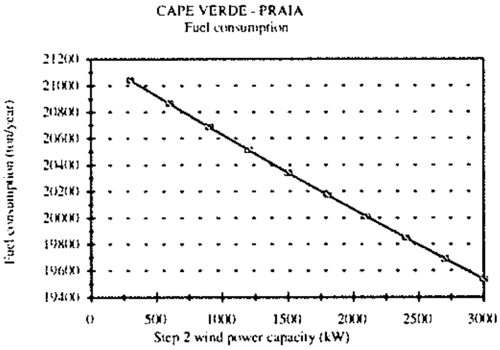


Figure 12.15

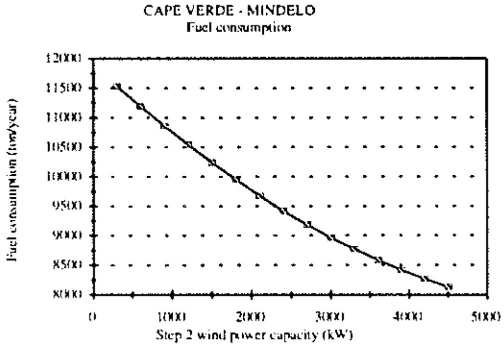


Figure 12.16

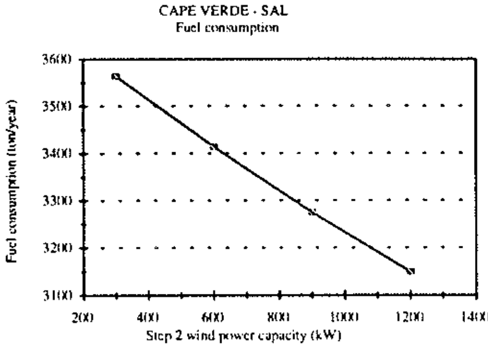


Figure 12.17

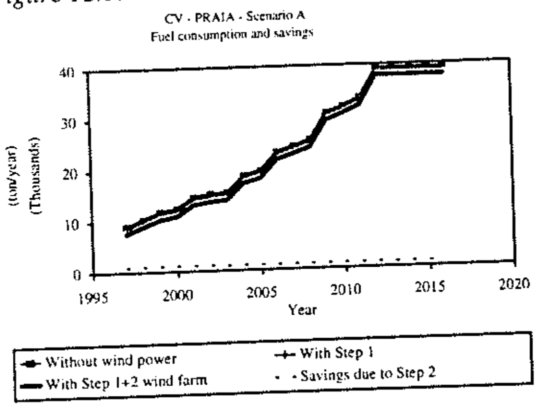


Figure 12.20

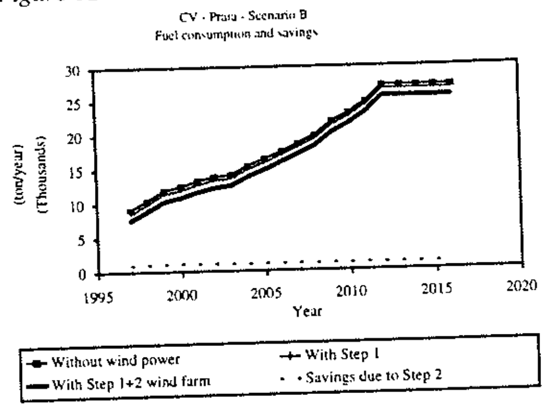


Figure 12.18

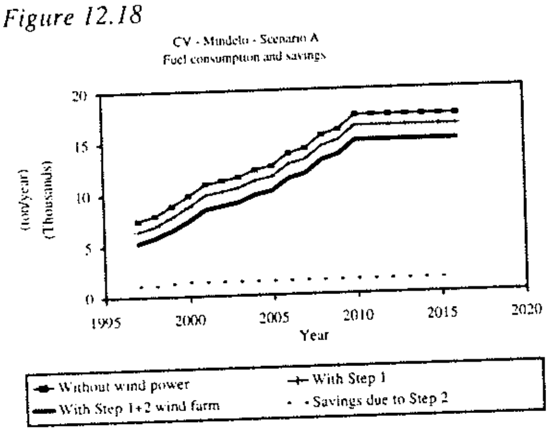


Figure 12.21

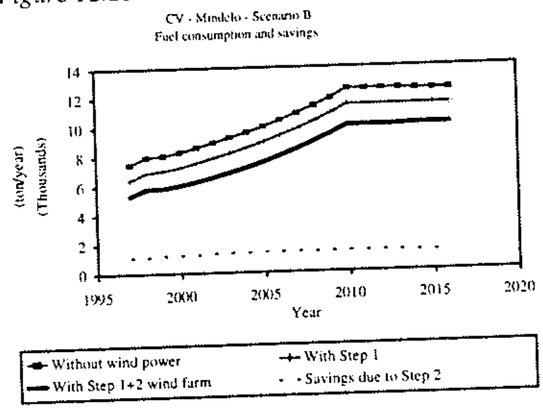


Figure 12.19

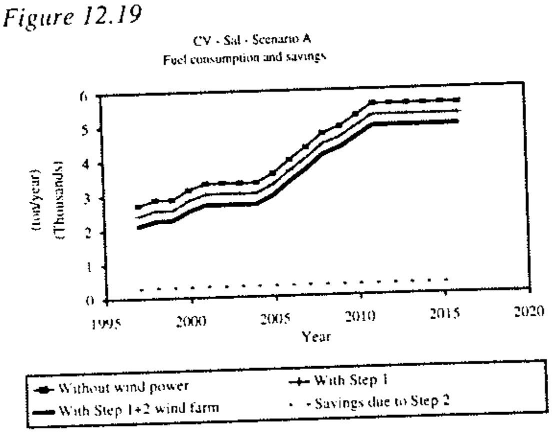
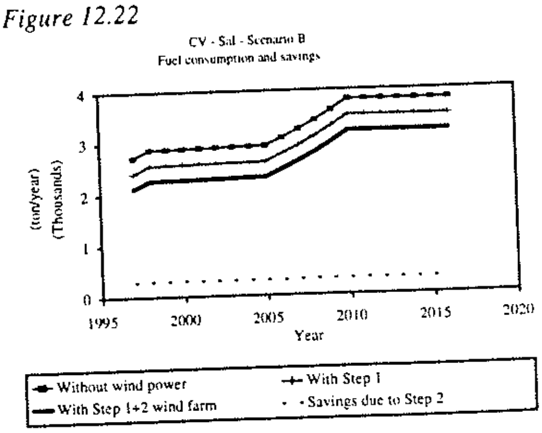


Figure 12.22



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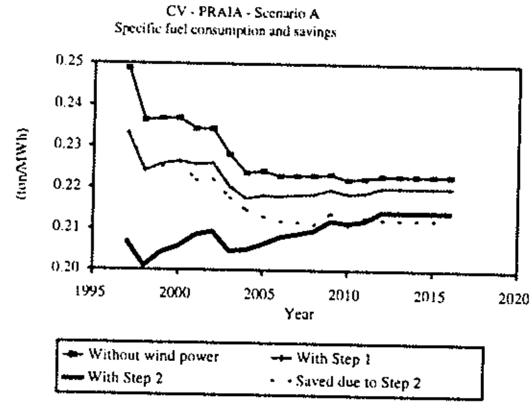

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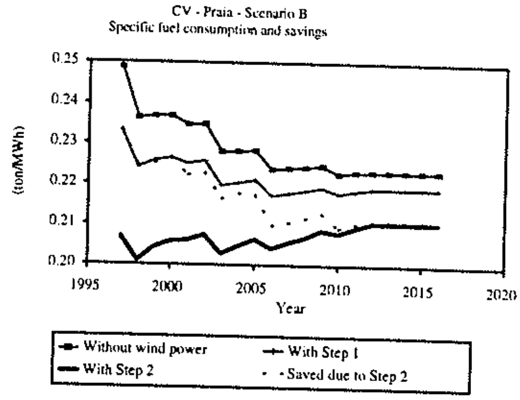


Figure 12.24

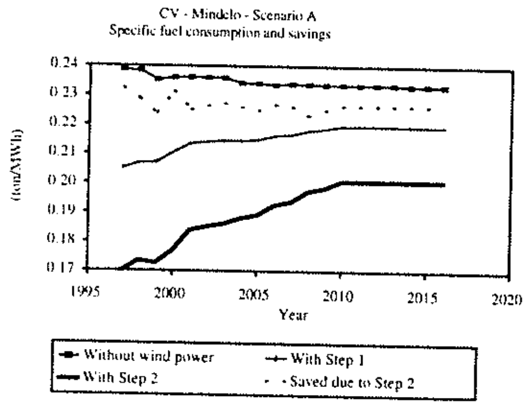


Figure 12.27

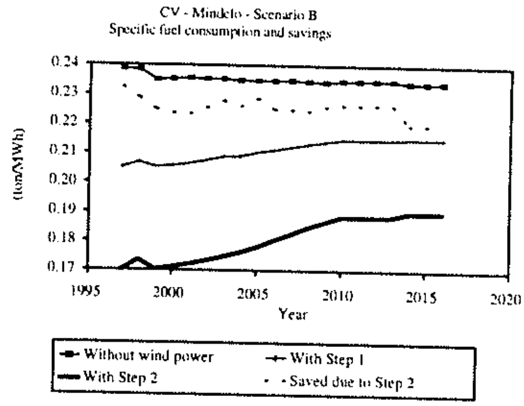


Figure 12.25

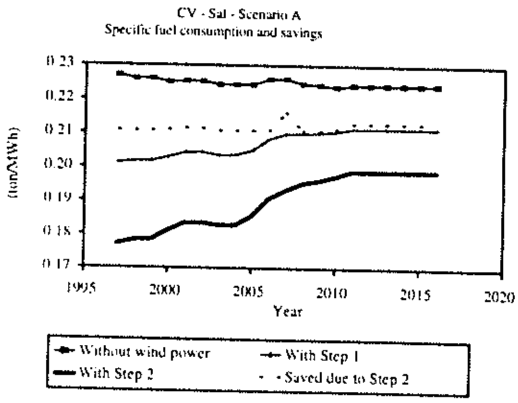
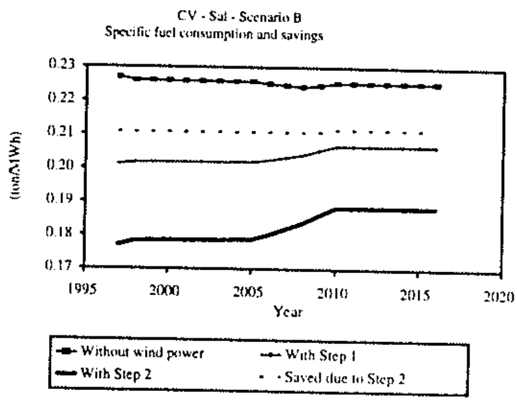


Figure 12.28



12.4 Savings in diesel power plant operation time

With the assumed power system operation strategy, the diesel power plant operators will assume a fraction of the wind power output to be firm. This means that in periods with sufficient wind power output, the spinning amount of diesel capacity may be reduced relative to the situation without any wind power. As the wind margin is assumed as high as 30 % (see section 12.1), the average output power of the wind farm must be more than 30 % of rated capacity before any firm power is assumed, i.e. only at wind speeds above 8 m/s. WINSYS simulations give the diesel power plant operation time as the annual sum of operation time for all the diesel generators.

For scenario A, figs. 12.29-12..31 show the relation between operation time and the installed Step 2 wind power capacity. Figs. 12.32-12.34 and 12.35-12.37 give the operation time year by year for the case of six 300 kW Step 2 wind turbines in Praia, four in Mindelo and two at Sal for scenario A and B respectively. As seen from the figures are the operation time reduced depending on the installed wind power capacity. The reduction in operation time per installed kW wind power is highest in Mindelo, and less in Praia and Sal. This is due to the higher wind speeds at the Mindelo wind farm site.

Figure 12.29

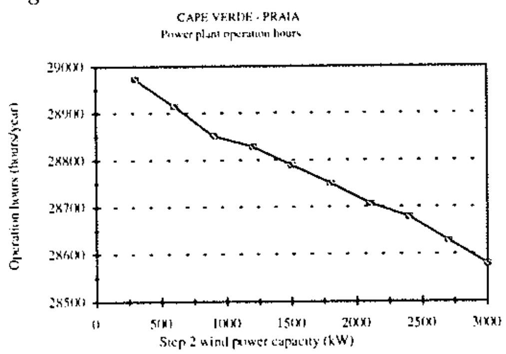


Figure 12.30

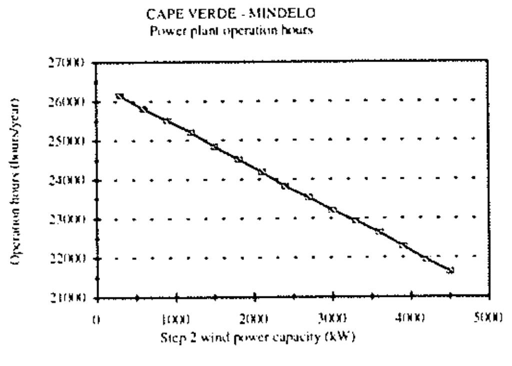


Figure 12.31

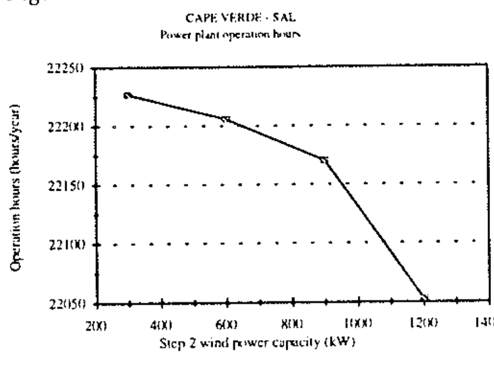


Figure 12.32

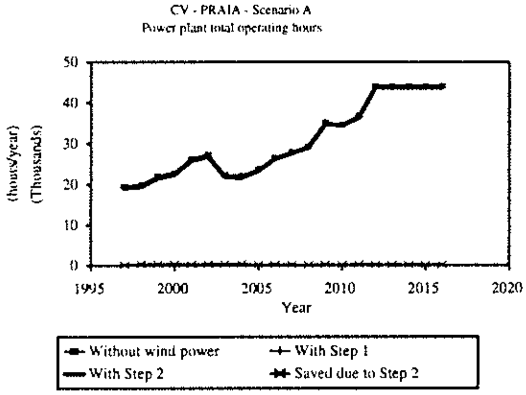


Figure 12.33

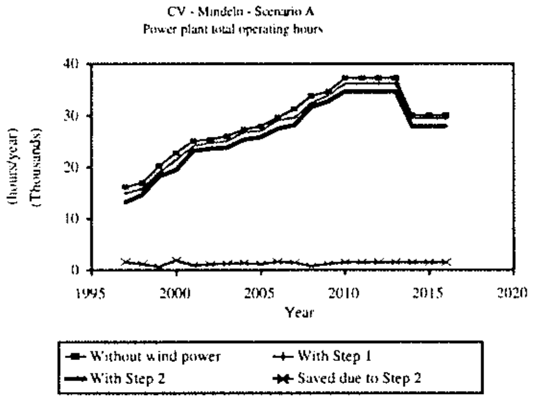


Figure 12.34

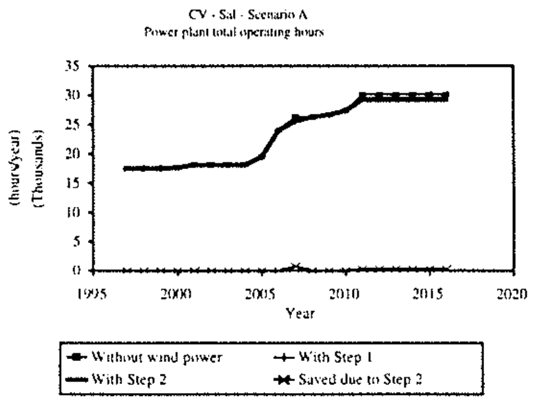


Figure 12.35

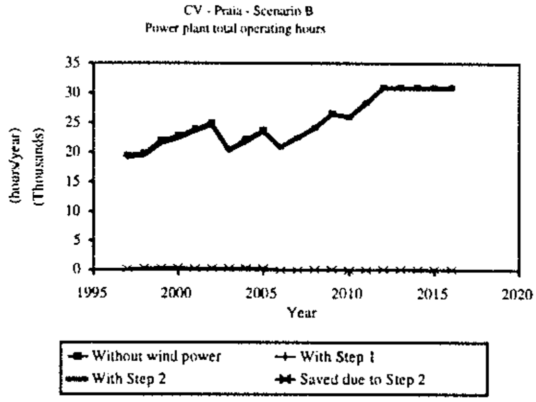


Figure 12.36

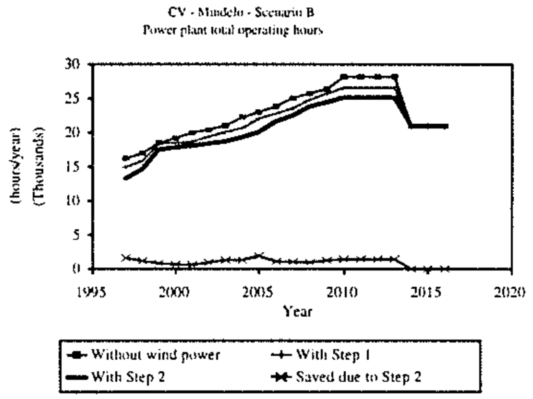
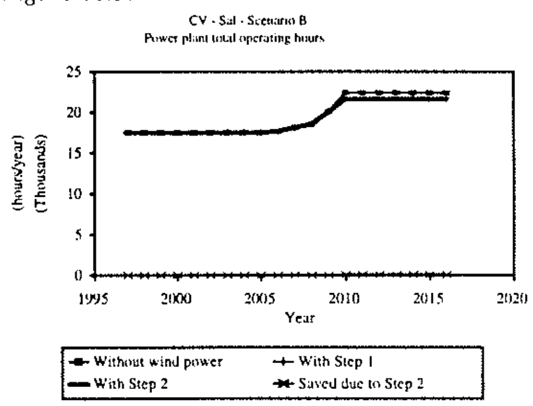


Figure 12.37



13. Economic analysis

The economic analysis consider the costs and benefits of the Step 2 wind farms project for Cape Verde. All results related to costs and benefits are given in constant money terms assuming Danish currency (DKK) and the present value time to be 31 Dec. 1996. All costs are specified assuming the price level of 1995. The following exchange rates are assumed:

8 000 ECV for 100 US$.
650 DKK for 100 US$.
1231 ECV for 100 DKK.

The discount rate used for the financial and economic analyses is 8 % p.a. in real terms. The relation between the discount rate in real terms, r, the nominal discount rate (market rate), i, and the inflation, v, is:

$$r = \frac{1+i}{1+v} - 1$$

The economic lifetime is set to 20 years. The technical lifetime of the wind turbines is expected to be the same.

Costs and benefits are calculated for the two development scenarios defined in section 7.

13.1 Determination of economic optimum number of Step 2 wind turbines

The economic optimum number of Step 2 wind turbines in each of the wind farms are determined as the number resulting in the lowest wind energy costs at scenario A assumptions.

The cost of the Step 2 wind farms energy output is estimated for each of the assessed sites, i.e. Praia, Mindelo and Sal, as the levelized production cost following the recommended practices as described by IEA /5/. The levelized production cost (LPC) is the cost of one production unit (kWh) averaged over the wind farm's entire expected lifetime.

$$LPC = TC \,/\, \sum_{t=1}^{n} AUE_t \cdot (1+r)^{-t}$$

Here, t is the year index, n is the lifetime, r is the discount rate, AUE is the wind farm annual utilized energy output as specified in section 12, and TC is the total cost discounted to present value:

$$TC = I + \sum_{t=1}^{n} (OM_t + SC_t + RC_t) \cdot (1+r)^{-t} - SV \cdot (1+r)^{-n}$$

Here I is the total wind farm investment, OM is the wind farm annual operation and maintenance cost, SC is the wind farm annual social cost (external cost), RC is wind farm retrofit cost and SV is wind farm salvage value.

13.1.1 Estimation and specification of assumptions

13.1.1.1 Wind farm investment

The investment estimate made for the Step 2 wind farms are based on actual prices from Step 1. The costs are divided into fixed costs, i.e. costs not depending on the wind farm size and variable costs assumed to be proportional to the installed wind power capacity. Table 13.1 gives the assumed investment costs divided into variable and fixed costs, whereas figure 13.2 gives the total investment cost as a function of the installed number of Step 2 300 kW wind turbines. The following text gives further description of each item in table 13.1.

- The assumed wind turbine investment cost of 1750 kDKK per 300 kW wind turbine corresponds to approximately 5800 DKK/kW. List prices per installed kW wind turbine capacity as specified by Danish wind turbine manufacturer in June 1995 give prices between 5000 and 8000 DKK/kW, with a majority around 5000 DKK/kW as also can be seen from figure 13.1.
- The grid connection investment cost is approximated to 250 kDKK per 300 kW wind turbine based on the estimate specified in section 10 for nine 300 kW wind turbines in Praia, six in Mindelo and two at Sal.
- Foundation and civil works are costs for making the foundation for each wind turbine.
- Transport is for transport from Denmark and to the sites.
- Spares and tools are for maintenance of the wind turbines during the defect liability period.
- After sales service is for wind turbine service by contractor during defect liability period.
- Fiber-optic costs are for fiber-optic cable. For Praia, 8 km of cable is assumed as to extend the connection from the existing diesel power plant and to the planned new diesel power plant. For Mindelo, 2 km of cable is assumed as to connect between the new Step 2 site and the Step 1 wind farm.
- Grid extension costs are for 95 mm^2 Cu-cable. For Praia, 2 km is assumed as to connect the wind farm directly to the existing diesel power plant and by this avoid the unfortunate disconnections as described in section 10. For Mindelo, 2 km of cable is assumed as to connect between the new Step 2 site and the Step 1 wind farm.
- Modify CMCS including 300 kW dumpload costs are for modification of the existing Central Monitoring and Control System as to include also the Step 2 wind turbines, i.e. basically soft ware modifications, and installation of a 300 kW wind turbine as to minimize the number of start and stops for dissipating excess energy and avoid unnecessary loss of wind energy.
- The met. station costs are for procurement and installation of a new meteorological mast with instrumentation at the Step 2 Mindelo wind farm site. The met. station is assumed to be as the met. stations for Step 1. For Praia and Sal no new met. stations are assumed.
- The wind farm building costs are for construction of a new building at the Step 2 Mindelo wind farm site. The building is assumed to be as the buildings for Step 1 or simpler. For Praia and Sal no new buildings are assumed.
- The access road costs are for construction of a new access road to the Step 2 Mindelo wind farm site. For Praia and Sal no new access roads are assumed.
- Design and manual costs are for contractors design works and preparation of manuals.

Figure 13.1 Danish wind turbines investment costs according to price list June 1994.

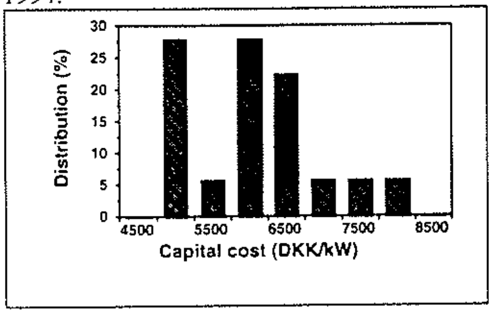
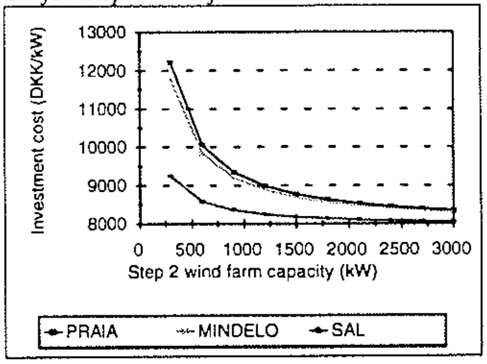


Figure 13.2 Estimated total investment per kW for Step 2 wind farms.



- Cable trench costs are for preparation of cable trenches. The costs are for 2 km of cable trench between 5th. Juhlo sub-station and the old diesel power plant in Praia, and for 2 km of cable trench between the Step 1 and 2 Mindelo wind farms. For the fiber-optic connection between the old diesel power plant in Praia and the planned new diesel power plant, cable trenches that must be prepared for grid connection / extensions are assumed to be utilized.

13.1.1.2 Wind farms operation and maintenance costs

The operation and maintenance costs are estimated to be 2.5 % each year of the investment costs of the wind turbines excluding the costs of supporting facilities. After 10 years a major overall (retrofit) is estimated to cost 10 % of the wind turbine investment.

13.1.1.3 Wind farms external costs

External costs due to the wind farms (noise, visual impact, etc.) are assumed to be negligible.

Table 13.1 Specification of assumed investment costs for Step 2 wind farms.

	PRAIA	MINDELO	SAL
Costs per 300 kW wind turbine	kDKK	kDKK	kDKK
Wind turbines	1750	1750	1750
Grid connection	250	250	250
Foundation & civil works	75	75	75
Transport	200	200	200
Spares & tools	50	50	50
After sales service	50	50	50
Sum costs per wind turbine	2375	2375	2375
Sum costs kDKK per kW	7.92	7.92	7.92
Fixed costs per wind farm	kDKK	kDKK	kDKK
Fiber-optic	480	120	0
Grid extension	330	330	0
Modify CMCS incl. 300 kW dumpload	200	200	200
Met. station	0	130	0
Wind farm building	0	50	0
Access road	0	50	0
Design & manuals	200	200	200
Cable trenches	80	80	0
Sum fixed costs	1290	1160	400

13.1.1.4 Wind farms salvage value

The salvage value, i.e. scrap value of the wind farms after the assumed 20 years lifetime is assumed to be zero.

13.1.1.5 Wind turbines energy output

The wind turbines annual energy output is assumed as estimated in section 12.

13.1.2 Calculation results

There exist an economic optimum size of the step 2 wind farms as the utilized output per wind turbine is reduced for increasing wind farm capacity due to the limited grid load, and the investment cost per wind turbine is reduced for increasing wind farm capacity, see also figs. 12.5-12.7 and fig. 13.2. WINSYS simulations for different Step 2 wind farm sizes at scenario A assumptions give the economic optimum number of 300 kW wind turbines. Figs. 13.3-13.5 show the calculated levelized production cost as a function of the installed Step 2 wind farm capacity. It is seen that minimum wind energy costs are achieved for about six 300 kW wind turbines in Praia, four in Mindelo and two at Sal.

13.1.3 Sensitivity analysis

Assuming six 300 kW wind turbines in Praia, four in Mindelo and two at Sal, the levelised production cost is calculated using WINSYS for a range of variations around scenario A assumptions. Figs. 13.6 - 13.8 show the levelized production cost sensitivity to changes in the assumptions. It is seen that the levelized production cost is very sensitive to variations in the annual average wind speed, e.g. for Praia, a 10 % lower annual average wind speed would increase the estimated levelized production cost from 0.40 DKK/kWh to 0.52 DKK/kWh.

Table 13.2 summarizes assumptions and compares results between scenario A and B.

Table 13.2 Summary assumptions and results for Step 2 wind farm cost of energy estimate. Retrofit is assumed after 10 years of operation. Lifetime is 20 years, discount rate is 8 % p.a. giving an annuity factor equal to 9.82.

	Praia		Mindelo		Sal	
Step 2 wind farm capacity (kW)	6x300		4x300		2x300	
Wind farm investment (DKK/kW)	5800		5800		5800	
Other investments (DKK/kW)	2817		3067		2767	
Total investment (DKK/kW)	8617		8867		8567	
O&M (% of wind farm investment)	2.5		2.5		2.5	
Retrofit cost (% of wind farm invest.)	10		10		10	
Salvage value (% of wind farm invest.)	0		0		0	
Scenario	A	B	A	B	A	B
Annual utilized energy (MWh/y)	4777	4774	5863	5679	1446	1426
Levelized production costs (DKK/kWh)	0.40	0.40	0.22	0.23	0.43	0.44

Figure 13.3

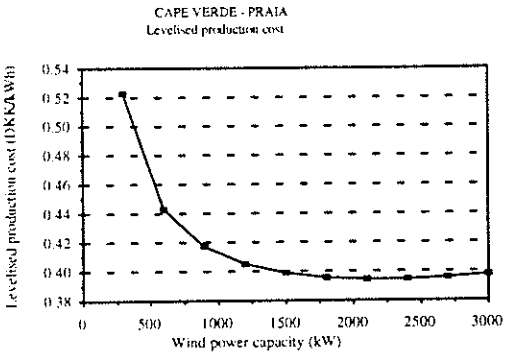


Figure 13.6

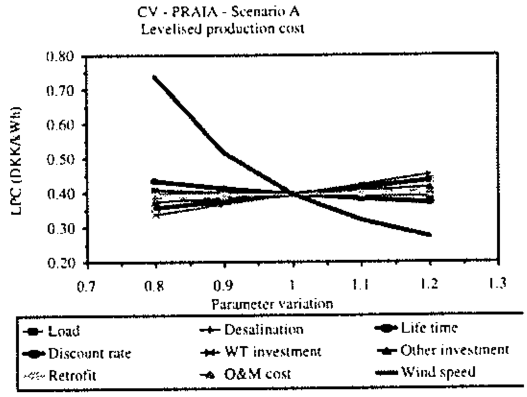


Figure 13.4

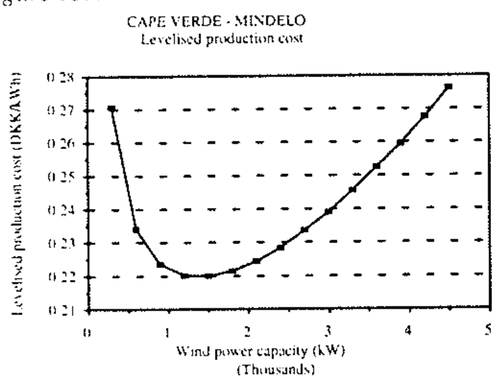


Figure 13.7

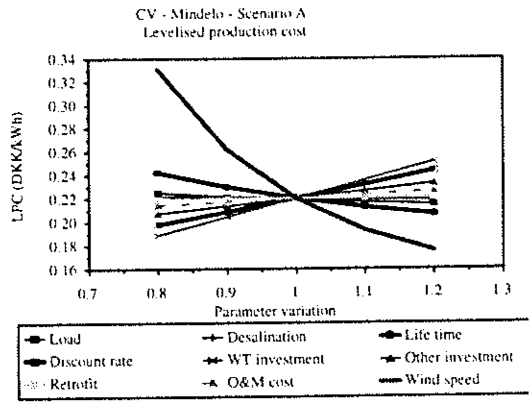


Figure 13.5

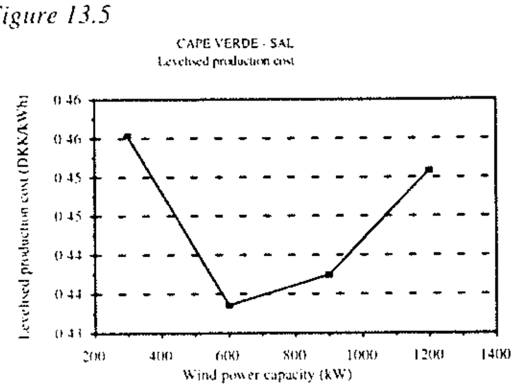
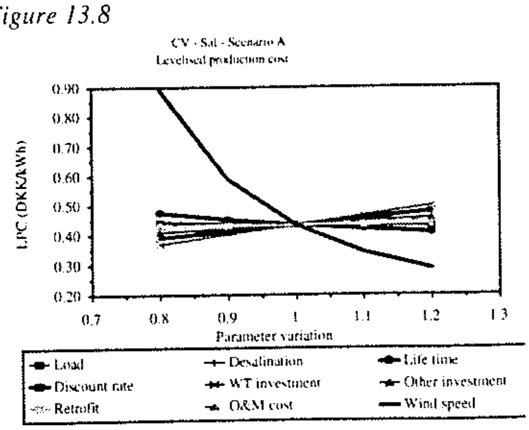


Figure 13.8



13.2 Cost - benefit analysis

The cost-benefit of the wind farm project is assessed in terms of net profit and internal rate of return.

The net profit (NPV) of the investment is calculated for the assessed wind farms of Praia, Mindelo and Sal, as the discounted difference between annual savings and costs over the assumed economic lifetime of the wind farms. The savings considered are related to:
- diesel power plant fuel costs,
- diesel power plant non fuel variable operation and maintenance costs,
- external costs (also called social costs) , e.g. connected to pollution and emission of greenhouse gasses (CO_2 emissions),
- wind power capacity credit.

The internal rate of return (IRR) of the investment is estimated for each of the assessed wind farms as the discount rate corresponding to NPV = 0.

13.2.1 Estimation and specification of assumptions

13.2.1.1 Fuel costs

The value of the fuel savings depend on the amount of fuel saved due to the wind farms and the cost of the fuel saved. The amount of fuel saved is estimated in section 12. The fuel cost is estimated as the actual economic cost excluding any subsidy or tax.

The fuel (heavy fuel and gas oil) for ELECTRA is supplied by ENACOL or Shell. Determination of fuel prices to be paid by ELECTRA is part of a price structure of all oil products in Cape Verde. The prices are stipulated by the government and the structure reflects the policy of some products carrying higher prices than necessary in order to subsidize lower prices for other products. The price structure does not include fuel for the airlines.

The costs for the oil companies to supply the fuels are determined as the price paid on the world marked and added costs of handling, storing, local transportation etc. If these costs add up to more than a maximum price decided by the Government, the Government pays the difference.

In 1994 ELECTRA paid a subsidized heavy fuel price of 14.0 ECV/kg in Mindelo and 16.8 ECV/kg in Praia. Based on discussions with the oil companies, relevant ministries and ELECTRA, the actual cost of heavy fuel delivered at the power plants for 1995 excluding any subsidy or taxation is estimated to 17.3 ECV/kg (1.40 DKK/kg) in Mindelo and 21.3 ECV/kg (1.73 DKK/kg) in Praia. The gap between the price for Mindelo and Praia is because the heavy fuel is first supplied to Mindelo and then reloaded for transportation to Praia. Sal power plant uses gas oil only.

In 1994, the maximum price of gas oil to be paid by ELECTRA was 19 ECV/l. As for the heavy fuel costs, the actual cost for gas oil delivered at the power plants for 1995 excluding any subsidy or taxation is estimated to 21.5 ECV/l corresponding to 1.75 DKK/l or 2.10 DKK/kg assuming a density of 0.84 kg/l.

Figure 13.9 Comparison of forecasted world market fuel costs and local fuel costs at Cape Verde. Local fuel costs are cost for fuel delivered at power plant.

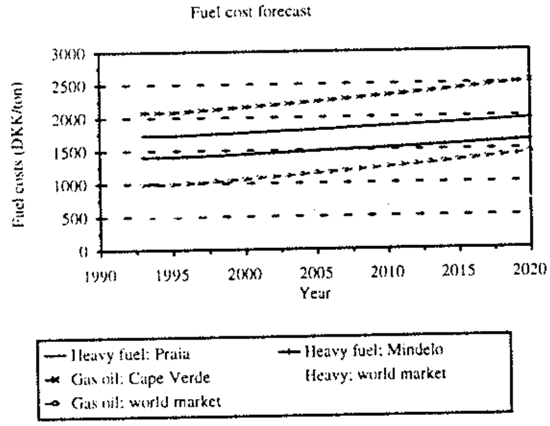
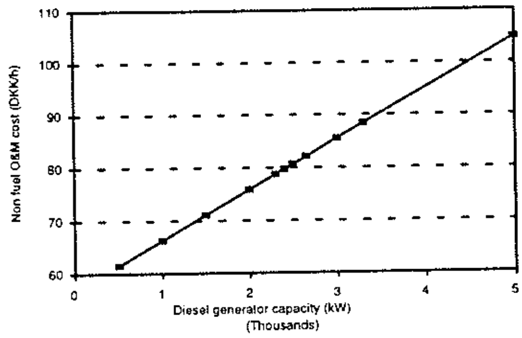


Figure 13.10 Relation between diesel generator capacity and non fuel operation and maintenance costs for ELECTRA diesel generator sets.



The future fuel costs are assumed to increase following an expected 1.5 % annual fuel cost increase at the world market, whereas the added costs for local handling, storing, transportation etc. are assumed to be fixed. Fig. 13.9 shows the estimated resulting fuel costs in DKK/t.

Comparing the estimated cost of fuel as delivered at the Cape Verde power plants with world market prices, e.g. 1995 prices fob at European market were around 12 US$/bbl (0.50 DKK/kg) for heavy fuel and around 20 US$/bbl (0.99 DKK/kg) for gas oil, and it is seen that transport to Cape Verde and local costs at Cape Verde are significant.

Appendix L gives further details on the fuel cost calculations.

13.2.1.2 Non fuel diesel power plant operation and maintenance costs

Based on data from ELECTRA, the non fuel variable operation and maintenance costs for the diesel power plants are assumed to depend on the generator set capacity as shown in figure 13.10. Diesel power plant non fuel variable operation and maintenance costs is saved in case the wind farms power output causes less operation time for the diesel generator sets, see also section 12.4 and figures 12.32-12.37.

13.2.1.3 Capacity credit

Following the analysis in section 11, the wind farms can be assigned a capacity credit as they reduces the power supply loss of load probability. The capacity credit or firm power from the wind farms assuming six 300 kW Step 2 wind turbines in Praia, four in Mindelo and two at Sal was found to be 24 % of the installed wind power capacity in Praia, 44 % in Mindelo and 18 % at Sal. The analysis also showed that the capacity credit in percent of the installed wind power capacity is not changed significantly as a function of the number of the assumed wind power capacity for Praia and Mindelo, whereas for Sal the relation may be approximated by assuming the relation 24-1.6N, where N is the number of Step 2 300 kW wind turbines.

Based on data from ELECTRA, the investment costs for diesel generator sets in the range around 3 MW are assumed to be 4000 DKK/kW. The capacity credit expressed in DKK for the wind farms assuming six 300 kW Step 2 wind turbines in Praia, four in Mindelo and two at Sal becomes 1 728 kDKK for Praia, 2 160 kDDK for Mindelo and 504 kDDK for Sal.

The capacity credit is credited at the same time as the investment.

13.2.1.4 External costs

External costs of electricity production are those borne by society and not reflected as a direct production cost. External costs are also called social costs and may be connected to environmental damage, nuisance to people, effects on employment etc.

It is accepted that electricity production from fossil fuels causing pollution and emission of greenhouse gasses (CO_2) imposes external costs. Whereas the theoretical determination of the external costs are still uncertain, many countries and organizations have decided to put a tax on emission of CO_2.

In Denmark, the Government has put a CO_2 tax on fossil fuel based electricity production at 0.10 DKK/kWh. In the future, there may be an international agreement to put tax on world market fuels as to internalize the external costs connected with combustion of fossil fuels. Presently, international funding agencies pays increasing attention to the environmental impact of any project considered for support. Most notably, the World Bank GEF (Global Environmental Facility) offers grants of upto 20 USD per ton saved CO_2. Pending on the detailed fuel and power plant specifications, this corresponds roughly to 0.10 DKK per kWh of saved electricity from fossil fuel plants.

The Step 2 wind turbines at Cape Verde reduces pollution and CO_2 emission as a consequence of reducing the diesel generators load and fuel consumption. Neglecting any other positive effect the Step 2 wind turbines may impose on the society in terms of employment, trade balance etc., and assuming as a rough estimate, that the reduced pollution and CO_2 emission corresponds to an external saving of 0.10 DKK per kWh of utilized wind energy output, the resulting net present value and internal rate of return of the Step 2 wind turbines are increased correspondingly as can be seen from table 13.3.

13.2.2 Calculation results

Table 13.3 summarizes the present value costs and savings for scenario A and B with and without external costs. It appears from the table that the Step 2 wind turbines will give an

Table 13.3 Summary assumptions and results for Step 2 wind farm economic cost-benefit analysis. Lifetime is 20 years, discount rate is 8 % p.a. giving an annuity factor equal to 9.82. All costs are discounted to present value.

	Praia		Mindelo		Sal	
Step 2 wind farm capacity (kW)	6x300		4x300		2x300	
Step 2 wind farm total costs (kDKK)	18556		12671		6155	
Scenario	A	B	A	B	A	B
Annual utilized energy (MWh/y)	4777	4774	5863	5679	1446	1426
Fuel savings (kDKK)	18514	18491	19340	18660	6695	6585
Non fuel O&M savings (kDKK)	237	187	1078	903	53	12
Capacity credit (kDKK)	1692	1692	2124	2124	422	422
Net present value (kDKK)	1887	1814	9871	9016	1015	864
Internal rate of return (%)	9.8	9.7	20.5	19.4	10.6	10.3
External savings (kDKK)	4690	4687	5756	5576	1420	1400
Net present value (kDKK)	6577	6501	15626	14591	2435	2264
Internal rate of return (%)	13.8	13.8	27.0	25.7	14.1	13.7

economic benefit for both scenarios. With the exception of results for Praia, the fuel savings alone actually are sufficient for creating a positive result. Taking account for also non fuel O&M savings, capacity credit and externalizes, the economic result of the Step 2 wind farms becomes very attractive.

Detailed printout of results are found in Appendix I, J and K.

13.2.3 Sensitivity analysis

Assuming six 300 kW wind turbines in Praia, four in Mindelo and two at Sal, the NPV and IRR is calculated using WINSYS for a range of variations around scenario A assumptions and neglecting external costs. Figs. 13.11 - 13.13 and 13.14 - 13.16 show the NPV and IRR sensitivity to changes in the assumptions. It is seen that both the NPV and the IRR is very sensitive to variations in the annual average wind speed.

The results are also sensitive to the assumed relation between present value time, and timing of investment and benefits. The calculations assume a present value time of end 96, and that the investment is made end 96 just before the Step 2 wind turbines start operation, and operation is credited at the end of each year thereafter. Assuming instead that the present value time is mid 96, and that the investment is made end 96 just before the Step 2 wind turbines start operation, and operation is credited mid each year, the investment should be discounted to present value (i.e. reduced with 4 % assuming an annual discount rate of 8 %) resulting in less present value costs and more attractive results.

Figure 13.11

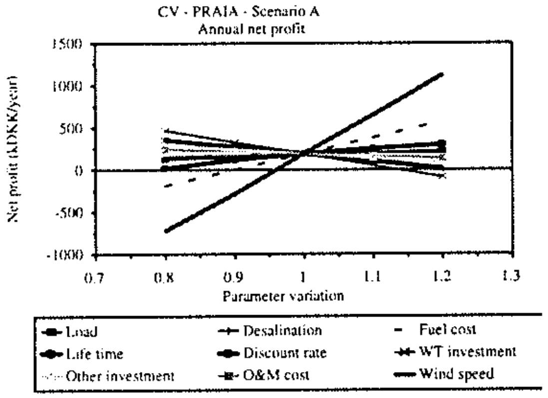


Figure 13.12

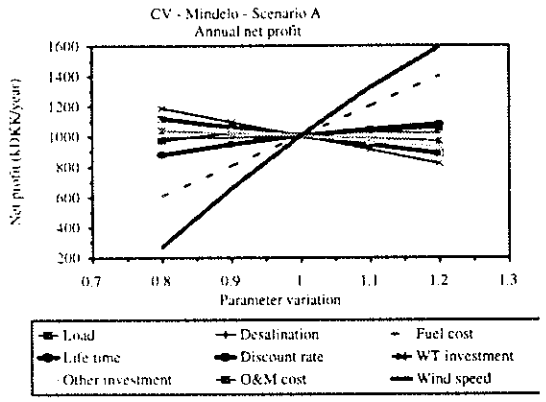


Figure 13.13

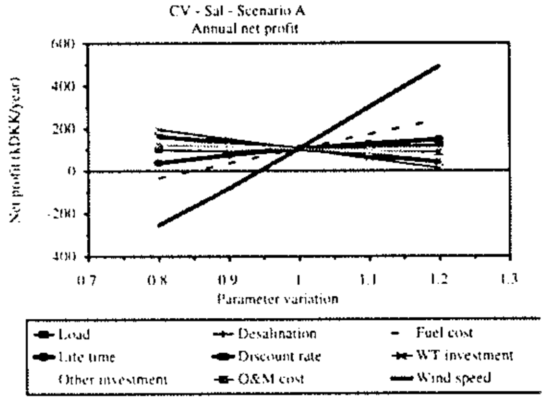


Figure 13.14

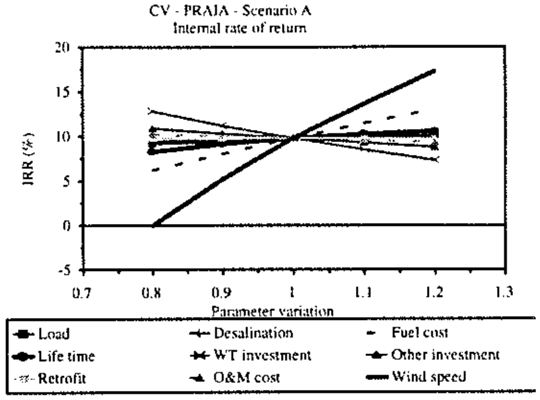


Figure 13.15

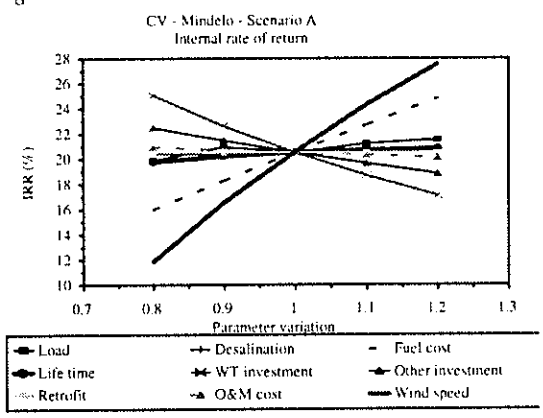
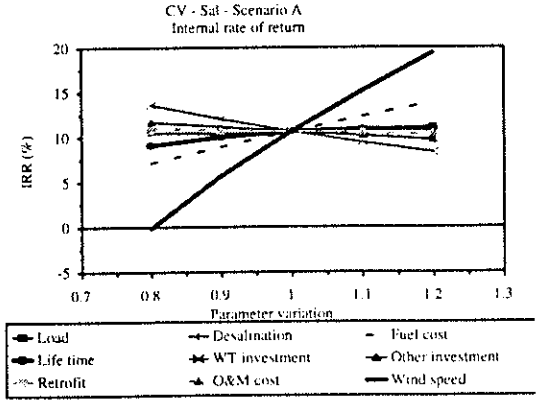


Figure 13.16



14. Financial analysis

The financial analysis consider the costs and benefits of the Step 2 wind farms project for ELECTRA. The assumptions for the financial analysis are as for the economic analysis except for fuel and external costs.

In the financial analysis, the fuel costs are assumed to be the price as paid by ELECTRA which is different from the actual cost of fuel to the Cape Verde society due to subsidy. The 1995 heavy fuel price for ELECTRA are assumed to be 14.0 ECV/kg of heavy fuel at Mindelo and 16.5 ECV/kg at Praia. At Sal gas-oil only is used. The 1995 price of gas-oil for ELECTRA is assumed to be 19.0 ECV/l. The fuel prices for ELECTRA are assumed to increase with 1.5 % p.a. during the analysis period. Comparing the forecasted fuel prices as they appear to ELECTRA with the forecasted fuel costs as they appear to the Cape Verde society in section 13, it is seen that the fuel subsidizes paid by the Cape Verde government are assumed to be reduced narrowing the gap between the actual fuel costs and the price paid by ELECTRA.

External costs are not applicable for the financial analysis.

The financial analysis does not consider impact on different options for financing the project, nor does it consider possible additional project costs for monitoring of project performance, dissemination of project results and other additional costs due to the particular nature of the project. This leads to that the investment costs considered for this financial analysis are as for the economic analysis, and the financial cost of wind energy become equal to the economic cost of wind energy.

The financial net present values and internal rate of return become less than the corresponding economic values as the value of the fuel savings due to subsidy are less for ELECTRA than for the Cape Verde society.

Table 14.1 summarizes the results of the financial analysis.

Detailed printout of results are found in Appendix I, J and K.

Table 14.1 Summary assumptions and results for Step 2 wind farm financial cost-benefit analysis. Lifetime is 20 years, discount rate is 8 % p.a. giving an annuity factor equal to 9.82. All costs are discounted to present value.

	Praia		Mindelo		Sal	
Step 2 wind farm capacity (kW)	6x300		4x300		2x300	
Step 2 wind farm costs (kDKK)	18556		12671		6155	
Scenario	A	B	A	B	A	B
Annual utilized energy (MWh/y)	4777	4774	5863	5679	1446	1426
Levelized production cost (DKK/kWh)	0.40	0.40	0.22	0.23	0.43	0.44
Fuel savings (kDKK)	15808	15786	17140	16548	6350	6246
Non fuel O&M savings (kDKK)	237	187	1078	903	53	12
Capacity credit (kDKK)	1692	1692	2124	2124	422	422
Net present value (kDKK)	-819	-891	7670	6904	670	525
Internal rate of return (%)	7.2	7.2	17.6	16.6	9.7	9.4

15. Risk Analysis

According to the agreement a

> *risk analysis of all important assumptions related to objectives, output, input, rentability, project implementation and operation*

has been carried out identifying factors which may prevent the project to reach the specified goals, i.e. primarily to produce a certain amount of electricity from wind at a presumed cost, but also to provide the intended know-how transfer to ensure sustainability and development.

A number of items have been identified which are important in order to attain the project goals, and relevant information has been collected on which the analysis - qualitatively - has been carried out, and from which the conclusions concerning the most important items are drawn. Finally, some recommendations are given which may reduce the risks of not reaching the objectives of the project.

The items in the list below have been identified as those which in certain circumstances may hinder, that the wind farms established in Step 2 of the project will reach the goals and expectations stated in the proposal - specified by the Draft Project Document. It is obvious, that the problem has a time dimension: namely the period during which the wind farms are established and put into operation - covered by the warranty of the manufacturer - and the period of "normal" operation in which the manufacturer will have to be paid if he shall back up the operation or carry out maintenance or repair. In the following the main focus will be on the long term, as the warranty period in any case (and hopefully) is short compared to the lifetime of the WTs. This also means, that the risk analysis concentrates on the longest period - 10-20 years -in which the largest part is produced, say 80-90% of what the WTs are supposed to generate.

The following list shows items which could be studied and included in the risk analysis. Data were compiled during a mission to Cape Verde in addition to available reports.

- Land-ownership
- Manning of the central administration as well as the sites and their responsibilities like
  - project organization
  - transfer of responsibility from engineering to operation departments
  - restructuring of ELECTRA
  - consequences of co-production of power and water
- Budget limits, partition of income between operation and investments
- The importance of training
- Strategy for the operation of the combined wind and diesel production system
- Availability of
  - power and communication lines
  - spare parts
  - crane
- Experience from established projects
  - experiences from Step 1 of this project

- Ponta d'Aguas operation in the past and transfer from INIT to ELECTRA
- experiences from Assomada
- experiences from other projects

However, the following analysis is reduced to those items contributing significantly to project risks.

15.1 Elements analyzed in the risk analysis

The items which were found most important are discussed, and some conclusions are drawn in the following sections.

The various items have very different impact on the electricity production and the economics of the project. Some concern the operation of a single WT for a relatively short period of time, others will influence many WTs simultaneously. Thus e.g. the unavailability of a certain spare part will keep a single WT out of service until provided, whereas insufficient training may cause a wind farm to produce below optimum for a long period. The latter loss may well be much larger than the former, but is revealed only if the production statistics are analyzed carefully.

As an example the following two situations may be compared:

1. A wind farm with five identical WTs is operated in a non-optimal way causing a loss of production of say 5%. This loss will not be seen in the daily operations, only a very careful analysis of the operation log together with logged wind conditions may reveal the loss
2. One of the WTs is out of service for a month due to lack of some spare part. The production loss for this particular WT is ~8% on a yearly scale and for the farm ~2%.

The latter incidence will be seen immediately contrary to the first situation.

A quantitative comparison of various causes and their consequences are nearly impossible, and in the following a qualitative analysis is given along with some recommendations. But the example points out the importance of the allocation of resources to the various activities in the company.

15.1.1 Land-ownership

Land-ownership to the area on which the farms are established, is crucial to the future operation and maintenance as well as the economic outcome. Therefore, regardless of how the future structure of ELECTRA will look, this item should be clarified.

The following items are important:

- right of way, both for transport of items to and from the wind farm and for power and control cables
- no-right-of-way for others which could disturb or destroy the operation of the sites - the WTs as well as connections for power and communication.
- protection of the free wind against future obstacles like buildings.
- royalty or payment in some way of the production or a free delivery of a certain amount of the production to the present landowner (e.g. the municipality)

All items may - if they are not settled satisfactorily - hinder a continuous, stable, and economic production.

If land-ownership is not established in a satisfactory way, the future utilization of the particular wind farm could be hampered, both regarding the wind resources and the operation and maintenance.

It seems that the municipalities are willing to transfer the ownership to the Government, but not to ELECTRA. With the present structure, the consequences are limited but the situation is unclear if ELECTRA is privatized. On the other hand, if ELECTRA is privatized a transfer of land-ownership to ELECTRA - as a private company - is unthinkable without some sort of payment, e.g. a free amount of electricity or a royalty of the production. Therefore, the land-ownership could be transferred to ELECTRA or an agreement established between the concerned parties as soon as possible regarding the area which has been pointed out for the wind farm.

It is obvious that this subject influences the future economy of the wind farms through the claims for payments for the land which is used by the wind farm.

Conclusions

- Agreements concerning the land-ownership should be established as soon as possible in order to be able to assess the future operation and financial conditions.
- The impact of agreements concerning the land-ownership should be clarified, e.g. the influence of a royalty to municipalities from ELECTRA.

15.1.2 Restructuring of ELECTRA

The reconstruction of ELECTRA has been discussed for some years and several models for the future structure of the supply of electricity and water have been set up ranging from one single company - state owned or fully privatized - covering all islands to a fully "atomized" supply system with every municipality taking care of the local supply, maybe through contracts with ELECTRA.

Therefore, this subject has great implications on management, economic resources, and staff related to the wind farms. The scenarios which have been formulated regarding the future structure of the energy supply will of course also influence the operation of the wind farms. The burden of capital costs of all existing machinery etc. combined with regulated tariffs for electricity and water may cause financial problems, depending on the structure which is chosen. Presently, the tariffs do not allow for generating a turnover sufficient to support the operation costs. It may be suggested that some of the assets are written off in order to improve the financial state.

ELECTRA has received the WTs as a loan from the Government, and - depending on the future status of ELECTRA and of the ownership of the wind farms - the loan may have to be paid back and/or rented. This will influence the future operation through the budget: the necessary resources for maintenance, training, etc., must be available.

Transfer of responsibility from Engineering Department to Technical Department for operation

The responsibility and management of all planning and project implementation of wind farm projects are with the Engineering Department of ELECTRA. When the wind farms are well established, the duty concerning running and maintaining the WTs is transferred to the Technical Department.

The important point to consider is to what extend will the knowledge collected during the planning and construction of the wind farms be transferred? Especially two points are essential:

- the experience gained during the planning and construction concerning the function, peculiarities, and weak points - which will influence the future ability to analyze and correct any failure in the operation and maintenance
- the personal contacts established between manufacturer, engineering firm, and owner which serve an immediate possibility to solve problems. It is well known, that such personal contacts will not last forever due to shift of duty etc. and further, that the contacts will be established again on a certain level as time goes. In a transition, however, problems may arise.

Depending on the way of managing the organization within ELECTRA, such a transition may be short and not influence the availability of the WTs.

Finally, the ownership of the WTs may, as mentioned elsewhere, influence the operation and maintenance, as well as training of personnel.

Co-production of water and electricity

A special item to consider is the co-production of water and power. According to the production method, the two products are coupled in the manufacturing process but are sold at prices which do not reflect the production costs. At present, the water is sold far below production costs. This means, that the overall budget must allocate resources for the water production, and consequently, that the power production, especially from the wind farms, may miss these for various purposes.

Conclusions

- At present the future ownership of wind turbines is somewhat unclear due to a possible restructuring of ELECTRA. This question is important concerning the responsibility for the operation and maintenance of the WTs combined with training of personnel.
- Likewise, the question of ELECTRA's financing of the WTs is unclear. If the assets are to be paid back, the economy of the company will be strongly influenced, and therefore the question should be settled.
- The present price structure for electricity and water in connection with the fuel prices (all fixed by the Government) determines the economic resources for ELECTRA and therefore also for the wind farms.
- Special attention should be given when the management of the wind farms is transferred from the engineering (planning) department of ELECTRA to the technical department

- The fuel savings in monetary terms due to wind energy production should be available and visible in ELECTRA's accounts

15.1.3 Budget limitations

According to the discussions above the available budget for the wind farms may depend on the new structure. The financial resources are important for the success of operation of the wind farms as they influence the following items:

- the number of trained personnel available for the operation and maintenance of the power systems, including the WTs
- the amount and quality of training offered to the staff
- the magnitude and management of the stock of spare parts

At present, a new accounting system is in preparation. The only available information concerning wind turbines is, that they are assigned a budget, but details are unknown.

Tariffs for electricity and water are decided by the Government. Further, fuels are subsidized. The price structure is such that ELECTRA has a deficit in the budgets. The consequence of producing wind power will be a decrease of this deficit. However, ELECTRA being a state owned company, it may be feared, that if great savings are obtained by means of the WTs, the funds for ELECTRA may be reduced correspondingly. This fact will not encourage ELECTRA to use great effort to optimize the wind production. On the other hand, once the wind farms are established, this fact will force ELECTRA to keep the turbines running in order to get the full advantages of the wind power.

Conclusions

- The yearly budgets should explicitly state the resources available for the wind farms related to staff as well as hardware.

15.1.4 Wind energy production estimation

The risks of not meeting the estimated annual wind energy production due to errors in wind resource assessments and inadequasi of the wind turbines technology is considered very small due to the site selection made and the documented performance of the Step 1 Wind Farms. It is, however, necessary to stress that the wind turbines must be of similar quality with a proven performance, i.e. approved in accordance with the Danish type approval requirements or similar (see section 8.5). Furthermore, it is recommended to verify by measurements the wind resources at the Selada Flamengo site, and activity which has been initiated April 1996.

15.1.5 Strategy for the operation of the combined wind and diesel power supply system

In order to maximize the wind energy production - and also to reach the goals of the present project - the power system should allow for WTs to generate as much power as possible at any time, depending on the instantaneous wind velocity. The production by the diesels will then be regulated such that the electricity demand is satisfied.

Fuel efficiency and technical minimum load:
The diesel engines are required not to operate below a certain minimum power level (the technical minimum load) and the efficiency is decreasing with decreasing power. Presently, the fuel efficiency of the diesels engines is a key factor fro power system operation, which means that operators may try to optimize the fuel efficiency of the diesel engines instead of optimizing the combined diesel and wind production, i.e. maximize the number of kWh per liter of fuel. Another factor which may counteract an optimal dispatch of the load between diesels and WTs, is the unit sizes proposed in the planning for new diesel capacity which are large units with a magnitude of ~3-5 MW, corresponding to a minimum operating level in the range of 1.2-2 MW due to the required technical minimum load of 40% of the diesel engines rated capacity.

Spinning capacity:
The power system operation must ensure sufficient capacity to supply the consumers electricity demand at all times - a certain amount of spinning reserve diesel capacity (including some reserve) is required to supply sudden demand increases. The amount of reserve required is known from experience. In a power system with wind power a different approach to determine the required spinning diesel capacity and reserve is needed, taking into account the fluctuations in wind power.

Training:
At present, the wind energy penetration levels at Praia, Mindelo and Sal cause no greater problems although the operators attitudes to the Step 1 wind farms have been different. With Step 2 wind farms, the proportion of wind power is increased, and training will be needed.

Training of the personnel in charge of the power systems and wind farms, of the personnel operating the systems, and of the teams carrying out maintenance and repair of the WTs will be very important.

As time goes, new personnel will inevitably substitute the former staff and be in charge of the various tasks concerning the management, operation, and maintenance of the power system and thus the wind farms. Thus, personal experience and knowledge may be lost and have to be transferred to or obtained by new staff.

Therefore, a regular training program has to be established taking into account, that training is expensive, both in money terms and considering the time spent to be trained in the new procedures.

Conclusions

- It is important to develop optimal power system operation strategies and tools, considering wind and load fluctuations, operational constraints of diesel generating sets, and power system fuel efficiency
- The sizes of new diesels should be decided taking the total power system cost efficiency and operation, including wind farms, into consideration

- Training courses for planners, managers, operators, and maintenance staff will be crucial for optimal exploitation of wind energy

15.1.6 Grid availability and communication line availability

The accessibility and availability of the electric grid is a necessary condition for the operation of the WTs.

The wind turbines are controlled locally by an automatic control unit in each wind turbine and remotely from the power station by the operator. The local control system monitors the performance of the individual wind turbine and performs safety actions and start/stop procedures of the particular wind turbine according to wind conditions and remote instructions, while the operator dispatches the load between diesels and stops WTs if needed. In order to carry out this job, measured data from the wind farm are transferred by cable to the power plant and presented to the operator.

Several types of grid or communication faults may decrease or stop the wind production, or make the dispatch non-optimal, some of which are mentioned below:

- closed down diesel power station or diesel units
- grid fault
- the particular HV-line connecting the wind farm and the power station is out of operation (e.g. for repair or, as seen in Praia, because of load share operations where parts of the grid are disconnected due to limited diesel production capacity)
- loss of communication between power station and wind farm (Mindelo in several months 1995-96)

Consequently, if for some reason any of these connections are out of service, the production is inevitably decreased. Likewise, the unavailability of a technician able to do the necessary repair jobs may decrease the production.

Conclusions

- If the power station, the grid or communication lines are out of service, the wind production will decrease or even be stopped. Trained maintenance and repair staff is a key factor to secure the supply.

15.1.7 Accessibility and availability of spare parts

Spare parts are very crucial for continuos operation and maintenance of the WTs and the accessibility will directly influence the availability of the wind power.

The spare parts range from small and cheap items like fuses to large and expensive units like the generator, blades and gear. Some parts are very rarely damaged whereas others have to be ordered regularly. The wind turbine manufacturer will have to be consulted on setting up a strategy for a) *which* parts should be in stock, b) *which* parts may be expected to be available in the local market and what are the specifications, and c) *which* parts will have to be ordered from the wind turbine manufacturer. The manufacturers experience and the record of operation of the chosen wind turbine are important.

The strategy should be determined from economic considerations, knowing that a stock of spare parts which limits the out-time of the wind turbines will require an investment.

Conclusions

The question of establishing a stock of spare parts should be addressed carefully and the following points are of importance and should be studied:

- The manufacturers policy and advise concerning spare parts in remote areas
- The correct mix between a central and distributed stocks of spare parts which are crucial for the continuous operation of the WTs
- Possibilities to manufacture certain parts locally
- The time needed for overseas supply of common spare parts
- Any restrictions to import spare parts
- Availability of foreign currency for payment of overseas assistance and spare parts
- Flexibility of the budget to carry high costs in some years
- Budgets for major overhauls

15.1.8 Availability of crane

A crane is an indispensable tool for the first erection of WTs, but may also be necessary for repair or renewal of heavy parts like blades, generator, and gear. The failure of having access to a crane when needed will directly influence the availability of the WT and thus its production.

Presently, the crane which is available and which was used for the establishment of Step 1 wind farms, must be assisted by a floating crane for the safe displacement from shore to ship and vice versa when moved from one island to another. Thus, in fact, two cranes - in addition to the transport vessel - have to be available for certain major maintenance operations, which on the other hand also happen rarely.

The following points are important to take into account in order to assess the availability of the crane for the wind farms:

- Will the cranes be available when needed?
- Will a vessel with the necessary capacity be available when needed (it will most certainly be on some other task when needed)
- What is the delay caused by waiting for transfer of the crane
- Is trained operators for the crane available

Conclusions

During the lifetime it may be foreseen that some maintenance or repair operations have to be carried out which demand assistance of a crane. There should be established arrangements which ensure that the cranes and a vessel could be made available within reasonable time.

15.2 Recommendations

The analysis of the factors which influence the project results leads to the following recommendations, which will decrease the risks that Step 2 of the project does not attain the objectives. The experience gained by the establishment of the Step 1 wind farms points to procedures which if successful and feasible, should be adapted by the Step 2. The following recommendations are made:

Organizational

- Independent of the future structure of ELECTRA it is important to clarify the future ownership of the wind farms and the land, where the wind farms are established. Agreements concerning the land-ownership should be established as soon as possible and terms have to be clarified both in case ELECTRA is privatized or not.
- The financing terms for ELECTRA and requirements to pay back loans (for the WTs) to the Government have to be clarified and settled.
- The yearly budget for ELECTRA should explicitly contain allocation for the operation and maintenance of wind turbines as well as for training.
- The yearly report from ELECTRA should contain information on the production by wind energy and the fuel savings ascribed to the wind farms, also in monetary terms.
- A policy of maintenance and repair should be established including the contents and structure of stocks of spare parts should be established
- The crane availability should be ensured
- A program for training of operation and maintenance staff as well as for engineers in planning and design of power systems with wind energy should be included

Technical

The design of grid connection of the wind farms should be taking into account the economic consequences of damage or disconnection,

- connecting to points which may be assumed to be in continuous operation
- securing cables and installations in such a way that they will not be unintentionally destroyed/damaged by nature or man

The communication lines between wind farms and power stations should be

- secured so as to avoid damage
- guaranteed a quick repair, e.g. in co-operation with the telecommunication company

The wind turbines should be

- of good quality - living up to Danish type approval requirements or similar
- from an experienced manufacturer

16. Project description

16.1 Objectives

The development objectives of the Government of Cape Verde as expressed by the Project Steering Committee are for Step 2 as for Step1:

- to produce electricity as clean and cost efficient as technically possible both in the short and the long term
- to reduce imports of fuels, thus reducing vulnerability to variations in fuel prices and possible global environmental fuel taxes as well as improving the balance of trade

The immediate Step 2 project objectives for ELECTRA and for the Government of Cape Verde are:

- to extend the Step 1 Wind Farms to the feasible limit of wind energy penetration
  - which is financially attractive for ELECTRA and economically viable
  - which will not cause any unacceptable steady state voltage or frequency deviations, dynamic instabilities or violations of operational requirements for diesel gensets, and
  - which may be simply integrated in the present power system operation methodology

16.2 Outputs

The project outputs should best possibly meet objectives listed in Section 16.1 above.

The main output of the recommended project is three Step 2 Wind Farms of 600 kW, 1200 kW and 1800 kW in Sal, Mindelo and Praia, respectively, and the corresponding electricity production, meeting the immediate objectives best possibly at the present conditions and assumptions.

Sketch designs of Step 2 Wind Farms are in principle shown in APPENDIX F. The sketch designs, investment and energy production estimates and other assumptions have been made for wind turbines of a type similar to the existing Nordtank 300 kW. It should be noted, however, that the wind farms and the project could be implemented with any approved wind turbine type in accordance with the requirements specified in Section 8 of this report and by any experienced contractor living up to requirements similar to those applied in Step 1.

The project outputs can briefly be listed as follows

- A report with results of analyses of the dynamic and transient stability and recommendation of protective measures if needed for the three power systems - Praia, Mindelo and Sal - with the Step 2 Wind Farms and grid expansions as shown in sketch designs in APPENDIX F and described in section 10.

- Wind turbines for Step 2 Wind Farms at Praia, Mindelo and Sal with installed capacities of 600 kW, 1200 kW and 1800 kW in Sal, Mindelo and Praia, respectively, including design, manufacturing, transportation, installation, commissioning, instructions and manuals for operation and maintenance as well as an after sales service programme in an 18 months defects liability period.

- All necessary electrical LV grid connections, HV grid extensions, substations and grid reinforcements (see APPENDIX F) as well as expanded wind farm monitoring and control systems and communication and new remote facilities in the diesel power station for recommendation of power system operation.

- One meteorological station for wind power forecasting at each of the Step 2 Wind Farms, located approximately 1-5 km northeast of the wind farm and communicating with the wind farm monitoring and control system and/or the remote facilities in the diesel power stations.

- An annual wind energy production and an impact on the electric power supply system as shown in Table 16.1 below :

Table 16.1 Estimated annual wind energy production and impact on the electric power supply systems of the recommended Step 2 Wind Farms at Sal, Mindelo and Praia

		Sal	Mindelo	Praia
Existing Step 1 Wind Farm capacity (kW)		600	900	900
Recommended Step 2 Wind Farm expansion (kW)		600	1200	1800
Production data for first year after installation (1997)	Step 2 util. wind energy output (MWh/year)	1366	4723	4146
	Step 2 fuel savings (t/year)	288	1098	968
	Step 1+2 total util. wind energy output (MWh/year)	2835	9303	6585
	Step 1+2 fuel savings (t/year)	598	2151	1542
	wind energy penetration (%)	24	30	18
Levelised production data for the 20 years lifetime (1997-2016)	Step 2 util. wind energy output (MWh/year)	1446	5863	4777
	Step 2 fuel savings (t/year)	306	1331	1046
	Step 1+2 total util. wind energy output (MWh/year)	2915	10473	7217
	Step 1+2 fuel savings (t/year)	617	2378	1581
	wind energy penetration (%)	16	19	7.5

- Improved power system monitoring and control facilities at the control rooms of Praia, Mindelo and Sal power stations, enabling
  - 1-10 minutes wind energy production forecasting including an uncertainty estimation
  - recommendations for power system operation, i.e. recommendations for power station operators of unit commitment - shut-down and start-up of diesel gensets

- Necessary access roads and civil constructions including wind turbine foundations and housing of equipment.

- Consumable spare parts for five years normal operation of the Step 2 Wind Farms.

- Supplementary equipment and tools necessary for erection, operation and maintenance of the Step 2 Wind Farms - excluding cranes and equipment for repair of fiber optic cables (it could be considered to include repair equipment for fiber optic cables depending on the development in this field in Cape Verde). The supplement depends on the type of wind turbine and the equipment and tools available for the Step 1 Wind Farms.

- Institutional support
  - Secretariat functions for the Project Steering Committee, including Project Progress Reports and Minutes of Project Steering Committee Meetings, both every 6 months.
  - A specification of design requirements for remote facilities - including algorithm - in power stations, supplying power station operators with recommendations for power system operation - i.e. unit commitment decisions.
  - A report assessing the power system performance and combined power system operation with Step 1 and Step 2 wind farms and recommendations on re-optimization of operational strategy for the power system after one year of operation of the Step 2 Wind Farms.
  - A study of the feasibility and recommendation on future wind farm expansion.
  - Assistance in dissemination of experience and results from operating power systems with high wind energy penetration
  - 2 engineers in Engineering Department trained in modeling and analysis for power system expansion planning and power quality assessment with high wind energy penetration
  - 2 engineers in Technical Department analysis and optimization of power system operation and power quality assessment with high wind energy penetration
  - the technical staff of the local delegations' wind energy departments trained in operation and maintenance of the Step 2 Wind Farms

16.3 Project implementation methodology

In accordance with ELECTRA and the Project Steering Committee preferences, it is recommended that the project implementation methodology and thus organizational setup, type of consultancy services and contractors as well as the activities involved in principle should be similar to what has been applied in the implementation of the Step 1. This implies:

- initial international consultancy services for dynamic power system analyses
- international consultancy services for construction of wind farms
  - design of Step 2 Wind Farms and electric grid connections and extensions
  - tendering and contracting
  - coordination and supervision of works
- wind turbine turnkey contract for
  - supply of wind turbines, expansion of wind farm monitoring and control systems, meteorological stations for wind power forecasting and remote facilities in the diesel power stations for recommendation on power system operation
  - equipment for HV and LV electrical grid interconnection, monitoring and control systems and all communications

  - transportation and installation of wind turbines, monitoring and control systems, meteorological stations and remote facilities in diesel power stations
  - design and construction of wind turbine foundations
  - supply of necessary tools, consumable spare parts for 5 years normal operation as well as manuals for operation and maintenance
  - training in operation and maintenance
  - an after sales service programme for the 18 months defects liability period
- ELECTRA and subcontractors are responsible for
  - access roads and landscaping
  - local civil works and construction of shelters and housing for substations and equipment
  - electrical grid connection and grid extension works and installation
  - operation and maintenance in accordance with contractual agreements
- international consultancy services for institutional support, coordination and training
  - adviser and secretary to the Project Steering Committee
  - analyse, suggest and specify remote facilities and algorithm in power stations for on-line recommendation to power system operators regarding unit commitment decisions
  - monitoring and analysis of power system performance and operation
  - follow-up analyses and assessment after one year of operation of Step 2 Wind Farms for recommendation on re-optimization of power system operation with wind power
  - assistance in dissemination of results
  - feasibility study and recommendation on future wind power expansion
  - training in analyses and design optimization of power systems with high wind energy penetration

Any ELECTRA assistance to the wind turbine turnkey contractor should be in the form of subcontracts to his turnkey contract at clearly defined conditions, e.g.:

> crane assistance for the erection of wind turbines should be at clear contractual conditions sufficient to maintain acceptable insurances of all equipment throughout the construction period, but the crane assistance itself (including inter-island shipment of the crane) should be made available from ELECTRA as the owner of the crane free of charge for the wind turbine turnkey contractor.

16.4 Activities

The project implementation will involved the activities listed below:

- *Initiation and coordination*
  - Verification of dynamic stability of power system at the proposed Step 2 Wind Farm sizes - a precondition for the project
  - Contract consultants for actual project implementation
  - Prepare Detailed Work Programme
  - Design of wind farms and electric grid connection and extension
  - Prepare Technical specifications

- Tendering and contracting of wind farm turnkey contract, equipment supplies & local works
- Overall coordination and supervision of works
- Progress reporting
- Project Steering Committee meetings
- Donor project monitoring and reviews
- Project Completion Report

- *Step 2 Wind Farms*
  - Commencement WT works
  - Procurement and shipment of electrical equipment to be used for local electrical works and wind turbine foundations
  - Construction - local works civil and electrical works
  - Design and manufacturing of wind turbines
  - Construction of wind turbine foundations
  - Shipment of wind turbines
  - Erection and installation
  - Wind farm grid connection and running in, including remote facilities in the power station
  - Commissioning, Test on Completion and Taking Over
  - Training in operation and maintenance
  - Manufacturers after sales service programme
  - Monitoring defects liability

- *Institutional support*
  - Monitoring and analysis of power system performance and operation
  - Specification of design requirements and algorithm for remote facilities in power stations for power station operators, which shall supply recommendations for power system operation - i.e. in particular regarding unit commitment decisions
  - Follow-up analyses and assessment after six months of operation of Step 2 Wind Farms for recommendation on re-optimization of power system operation with wind power
  - Feasibility study and recommendation of future wind power expansion of the three power systems
    - WT siting & wind farm layout
    - Identify alternative development scenarios, including possibilities for demand side (consumer) management and optimization of power system operation (manual or automatic)
    - System modeling
    - Economic, financial and risk analyses
    - Reporting
  - Assistance in dissemination of results - locally in ELECTRA and Cape Verde as well as internationally
  - Training in modeling, analyses and planning of power systems with high wind energy penetration

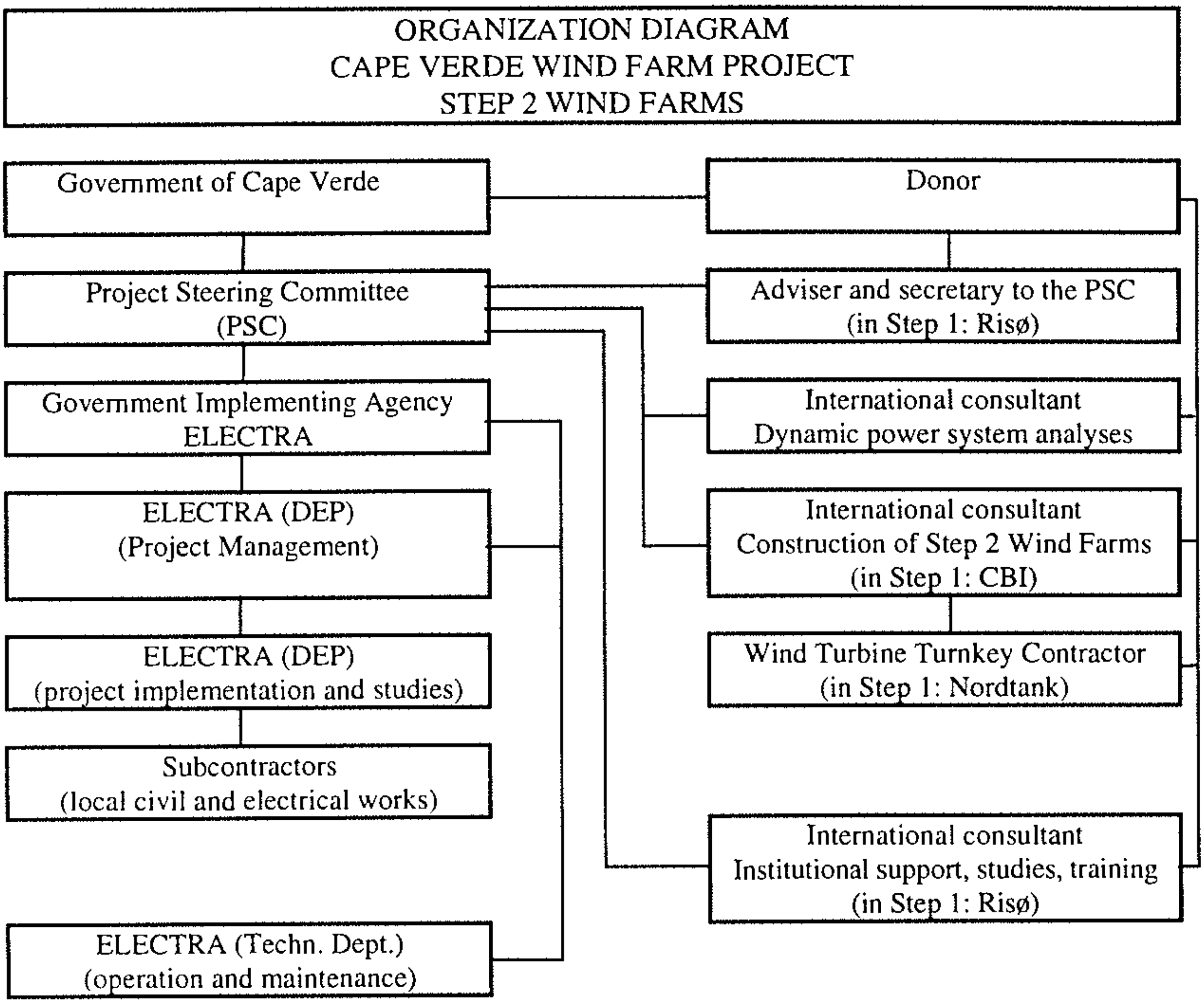
16.5 Budget estimate

The budget estimate for the project for implementing the proposed Step 2 Wind Farms is based on actual prices from Step 1. Details regarding wind farm investments are given in Section 13 of this report. All prices are at December 1995 price level.

Table 16.1 Budget estimate for proposed project - Step 2 Wind Farms

	PRAIA	MINDELO	SAL	TOTAL
Step 2 Wind Farms - installed capacity	*1800 kW*	*1200 kW*	*600 kW*	*3600 kW*
A. BUDGET FOR DONOR INPUT:				
Wind turbine turnkey contract	**kDKK**	**kDKK**	**kDKK**	**kDKK**
Wind turbines incl. installation, etc.	10500	7000	3500	21000
Grid connection	1500	1000	500	3000
Wind turbine foundations	450	300	150	900
Transport	1200	800	400	2400
Spares & tools	300	200	100	600
Equipment for fiber-optic communication	480	120	0	600
Equipment for grid extension	330	330	0	660
Modify CMCS incl. 300 kW dumpload	200	200	200	600
Met. station and remote facilities in power station	130	130	130	390
Design & manuals	200	200	200	600
After sales service	300	200	100	600
Training	250	250	250	750
Total - wind turbine turnkey contract	**15840**	**10730**	**5530**	**32100**
Technical assistance	**kDKK**	**kDKK**	**kDKK**	**kDKK**
contract 1 : Dynamic power system analyses				**350**
contract 2: Construction of Step 2 Wind Farms				**3000**
design of wind farms and grid				900
tendering and contracting				500
coordination and supervision of works				1600
contract 3: Institutional support				**3000**
secretary to the Project Steering Committee				750
specification of power system operation				500
monitoring of power system performance				300
re-optimization of power system operation				250
assistance in dissemination of results				200
feasibility study - future wind power expansion				750
training in power system analyses and optimization				250
Total - International consultants				**6350**
GRAND TOTAL - DONOR BUDGET (kDKK)				**38450**
B. BUDGET FOR CAPE VERDEAN INPUT:				
Local works, staff salaries, expenses	**kECV**	**kECV**	**kECV**	**kECV**
Wind farm building	0	625	0	625
Access roads	0	625	0	625
Cable trenching and laying	1000	1000	50	2050
Crane assistance incl. its transport	-	-	-	5000
Design, supervision, project management	-	-	-	2500
Land	-	-	-	0
Misc. expenses - local travels, shipments, etc.	-	-	-	5000
GRAND TOTAL - ELECTRA BUDGET (kECV)				**15800**

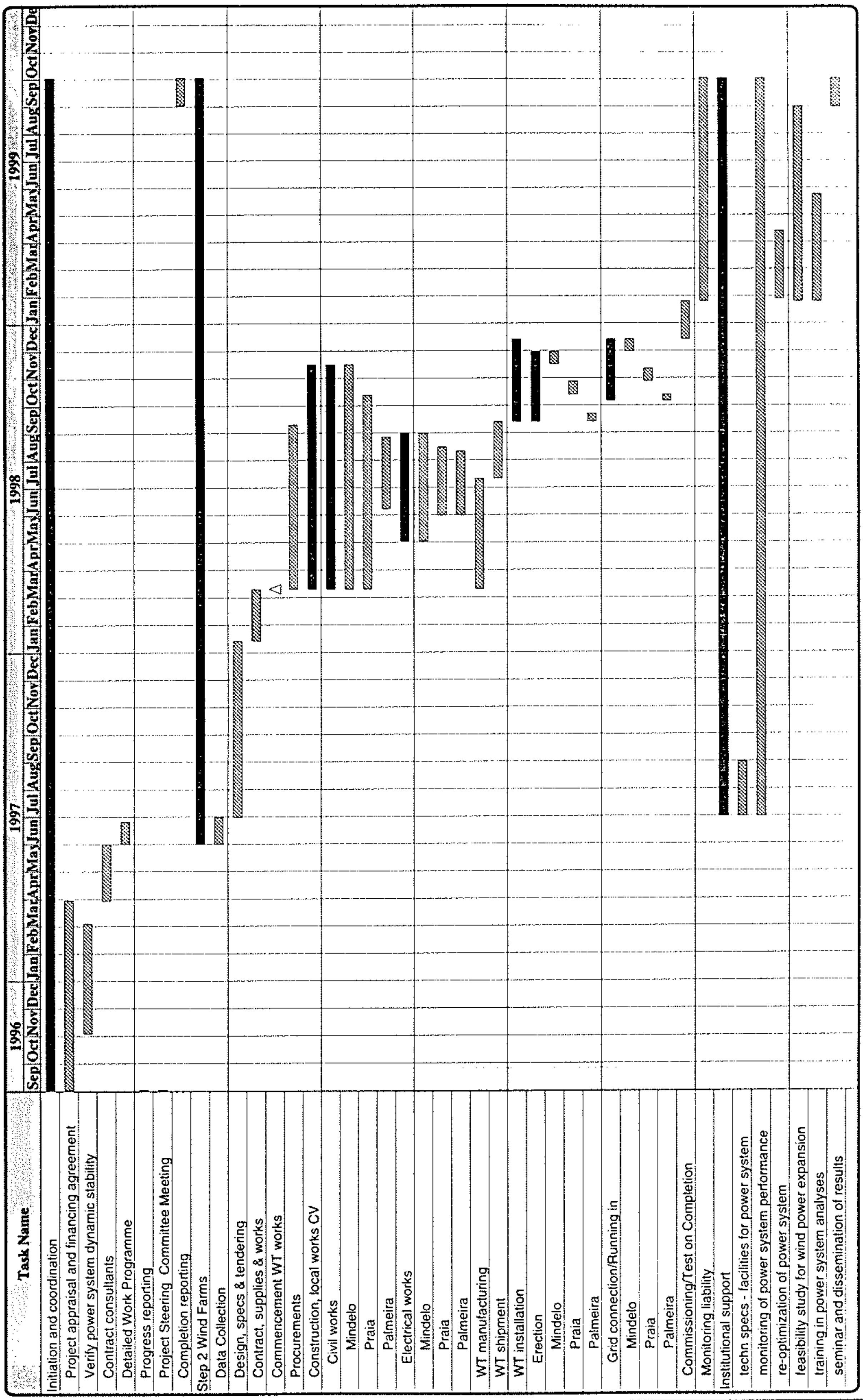
16.6 Project organization



16.7 Project Implementation Plan

A proposed project implementation plan based on the experience from Step 1 is shown on the next page:

Cape Verde Wind Farms - Step 2



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Page 1

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